EVALUATION OF ASPHALT AGING

IN HOT MIX PLANTS

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ABSTRACT

Asphalt concrete pavement tenderness, due to inadequate aging or unexpected soft consistency of the asphalt, has caused problems such as rutting, surface flushing, stripping, ravelling and segregation in Oregon highways over the past ten years. In order to identify the causes of the pavement tenderness, data were gathered from various construction projects throughout the state. As a measure of the aging in the mixing and placement process the following formula was developed to determine the percentage change in asphalt viscosity at the time of paving:

$$C = \frac{R - A}{B - A} \times 100\%$$

where, A = absolute viscosity of the original asphalt, B = absolute viscosity of the rolling thin film oven residue (RFTC) of the original asphalt, and R = absolute viscosity of the asphalt recovered from the mixture. Based on field observations of paving projects, no paving problems (tenderness) were experienced when "C" values were above 50 percent, some problems were experienced when "C" values were from 30 to 50 percent, and pavement problems were always experienced when "C" values were less than 30 percent. A value of 30 or higher was then used for acceptance on paving projects (OSHD Specification 403.39).

A number of variables were documented in the field to identify the cause of the indicated pavement tenderness. These included, testing delay, contractor operation, asphalt plant type, dust collection system, grade and supplier of asphalt cement, burner fuel type, asphalt concrete mix class, and limited mix temperature data. Special emphasis was

placed on the collection and evaluation of data on burner fuel contamination of asphalt. These variables were correlated against "C" values of 111 asphalt samples from 29 paving projects.

Results from the study indicated that the selection of burner fuel type is critical in producing a satisfactory mix. Some lower grade fuels (reclaimed oils), due to poor combustion, cause contamination of the mix by softening the asphalt. Low temperature in the mixing or aggregate drying process, especially in drum mixer plant burners, is detrimental to the mix. This will produce poor combustion of burner fuel and less aging. The overall operation and construction of asphalt plants, burner fuel type, mixing temperature and the use of bag house dust collectors, has a significant influence on the tenderness of the produced mix.

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INTRODUCTION

Background

Over the past ten years there has been an increase in hot mix asphalt concrete paving projects with tender pavements in Oregon. This tenderness, whereby the asphalt cement acts as a softer grade or slow setting asphalt rather than a normal paving asphalt, can cause serious rutting, surface flushing, stripping, ravelling and segregation in pavement surfaces.

A number of sources were suspect in causing the tenderness problem. These included new crude oil sources, the use of reclaimed burner fuel in dryers, low quality aggregate, lower mixing temperature, anti-stripping additives, use of vibratory compactors, higher moisture contents in mixes, and the introduction of drum mixer plants. However, contamination of the asphalt mixture was suspected as the primary problem. Possible sources of this contamination are at the asphalt truck tanks, paving plant cleanup, paving plant burner fuel, truck bed coatings, and paving machine cleanup.

Asphalt contamination is not a new problem in Oregon. In the 1950's asphalt hauling tankers were an occasional source of contamination, thus requiring the asphalt product to be accepted at the paving plant rather than at the supply source. Also in the 1950's and 1960's aggregate contamination from burner fuel was experienced in the aggregate dryer drum of batch plants. Occasionally the aggregate was found to be coated with burner fuel and was detected by placing the dried aggregate in solvent.

A study in California about the same time (Apostolos, et. al., 1974) concluded that unconsumed burner fuel apparently contaminated the asphalt in drum mixers and softened it. This was verified by adding various percentages of diesel oil to an asphalt, subjecting it to the Abson recovery process, and testing the recovered asphalt for penetration. The penetration increased with increasing percentage diesel.

A more recent study conducted for the FHWA (Von Quintus, et. al., 1982) compared the long-term performance of mixtures produced by the drum mixer and conventional batch plants. The limited data indicated that there may be a difference in the asphalt cement aging rate for asphalt concrete produced in the two types of plants. The data show that the initial asphalt cement hardening during mixing appears to be less in drum mixer plants than in batch plants. There is evidence to indicate that lower grade fuel oils could be contaminating the asphalt, resulting in higher penetration or lower viscosities. There is also evidence that the asphalt cement in materials produced by drum mixer plants may harden or age faster in the field, than the same material produced in a conventional batch plant.

Objectives

The primary purpose of this investigation was to gather data from various construction projects throughout the state in order to identify the causes of the pavement tenderness. Since burner fuel contamination was thought to be a major source of the problem, special emphasis was placed on collecting data relevant to this specific item.

As far as practical, projects with batch and drum mix plants, various asphalt grades and suppliers, various burner fuels, different contractors, and locations throughout the state were sampled.

Most importantly a method of measuring asphalt aging (or lack of) needed to be developed that could determine the change from the paving plant asphalt storage tank to the paving laydown operation.

IMPLEMENTATION

Development of the Aging Formula

In order to identify the cause of aging (or lack of), samples of asphalt cement were obtained prior to mixing and from the completed asphalt mix. Absolute viscosities were run on the original asphalt, that obtained from the rolling thin film oven residue (RTFC) and from asphalt recovered from the mixture. For each sample, the percent change in asphalt viscosity at the time of paving was determined by the following formula:

$$C = \frac{R - A}{B - A} \times 100\%$$

A = absolute viscosity (OSHD TM 417) of original asphalt used in production of the mixture,

B = absolute viscosity (OSHD TM 417) of rolling thin film oven residue (AASHTO T 240) for asphalt used in production of the mixture, and

R = absolute viscosity (OSHD TM 417) of asphalt recovered from the mixture (OSHD modified AASHTO T 170).

The absolute viscosity difference determined in the denominator (B-A) approximates the aging that would occur in a typical batch plant mixing and paving operation. The absolute viscosity difference determined in the numerator (R-A) gives the actual aging that occurred in the mixing and paving operation. Under normal circumstances the ratio of the two differences should be near 1.0 (or 100%). If there was contamination or other contributing factors that prevented aging, the ratio would be smaller or even negative. Excessive hardening or aging would be denoted by a large positive ratio.

Based on field observation of paving projects in Oregon over the past three seasons no paving problems (tenderness) were experienced when "C" values were above 50 percent, some problems were experienced when "C" values were from 30 to 50 percent, and pavement problems were always experienced when "C" values were less than 30 percent. Based on this experience a value of 30 or higher was considered acceptable (see OSHD specification 403.39 in the Appendix).

Data Collection

Starting in 1981, data were collected from 29 different projects in Oregon. A total of 111 samples were collected for "C" value from these projects. For each project, the contractor, mixing plant type, dust collection system, asphalt concrete mix class, asphalt cement supplier and grade, and burner fuel type were recorded. For each sample, where possible, the date of sampling and testing were recorded, the plant and street mix temperatures determined, samples of asphalt mix and asphalt cement taken to determine the various viscosities, and samples of burner fuel were taken. The mix samples generally were taken on the street rather than at the plant to give maximum opportunity for aging.

Unfortunately, in most cases field personnel did not always record the plant and street mix temperatures. In addition burner fuel samples were not taken at the time of asphalt sampling during the 1981 and 1982 seasons. Visual observations were also made of mixing and paving problems along with the characteristics of the final pavement.

On several projects, where tenderness problems developed and/or low "C" values (below 30) were determined, plant adjustments were made, such as burner position changed, plant temperatures increased, and various fuels such as diesel, propane, natural gas and reclaimed fuel oil tried.

At present, samples for "C" value determination are routinely taken as a check on the mixing and paving operation and for possible burner fuel contamination. These are at least taken at the beginning of production and when problems are suspected.

RESULTS

Aging in the Mixing Process

Since the asphalt cement is now accepted just prior to entering the mixer, and these tests indicated specification compliance, a limited number of tests were made on samples from the supplier's storage facility. No significant change in viscosity was detected between asphalt cement samples from the supplier tank and prior to entering the paving plant mixer.

When testing the viscosity of asphalt sampled just prior to entering the mixer and from mix sampled behind the paving machine, a wide range of "C" values were determined. These ranged form -58% to +224% with a mean of 62% and standard deviation of 53%. A total of 28 percent of the samples failed ("C" value below 30).

Some initial testing was performed to determine the aging caused by the paving operation alone. No significant change was found due to hauling and laydown.

Variables Influencing Aging

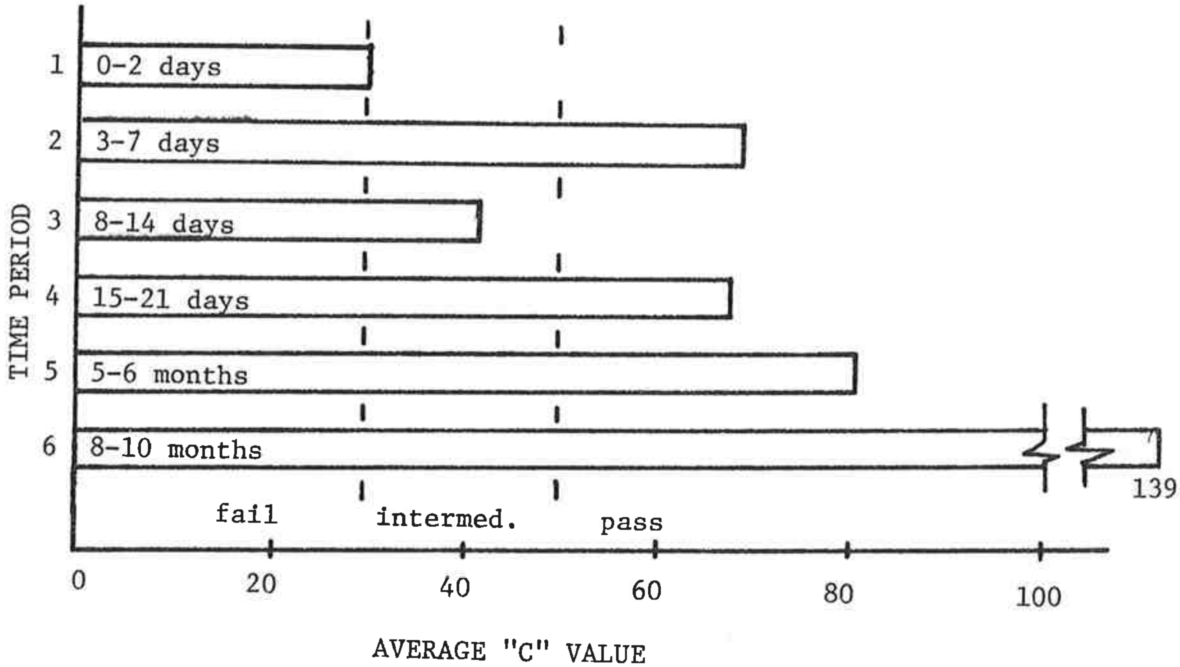
Once the aging process was determined to exist only between the mixer and the street, a number of variables were looked at in detail to determine their influence.

1. Testing Delay

During the construction season, due to the heavy testing demands, not all samples were tested immediately. The delay between sampling and testing was determined for each sample, with the results shown in Figure 1. Ten samples were stored for extended periods of time (over five months) and as a result gave high "C" values and no failures. Since this most likely reflects aging in storage and not due to the production and paving operation, these tests were rejected. In addition two other samples were rejected since the plant sample date and street sample date did not match. All subsequent analyses are based on 99 samples (maximum value = 183%, minimum value = -58%, standard deviation = 47%, with a total of 31% failures).

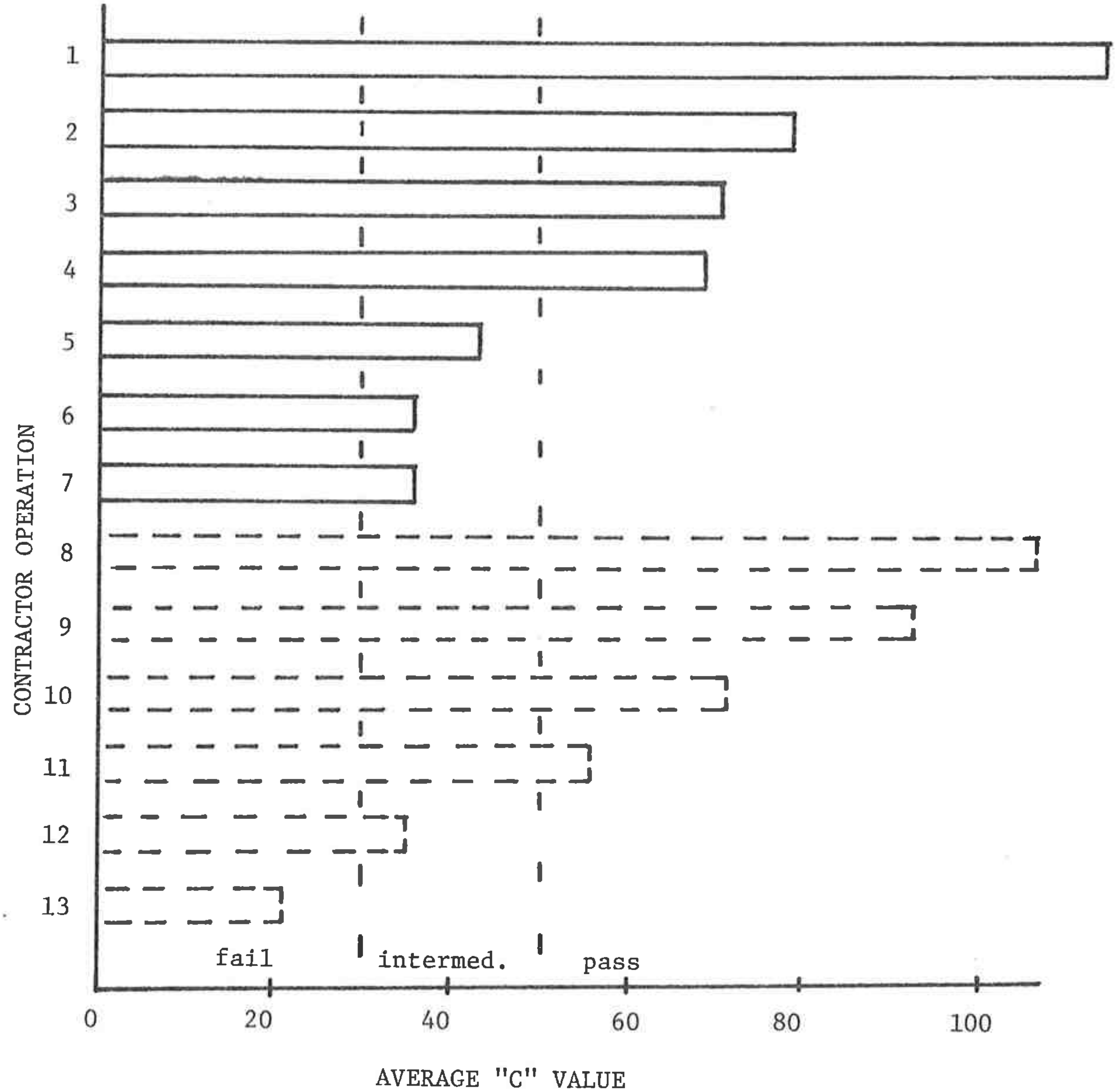
2. Contractor Operation

Samples were grouped by paving contractor regardless of the number of projects or if he had more than one plant. This grouping was intended to reflect the overall performance of the contractor's operation in the hope that those with problems could be identified and corrected. A graphical representation is shown in Figure 2. Those bars representing one or two tests are shown with dashed lines to indicate that the data is probably questionable.



Time period	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	25	31	28	64
2	31	69	61	23
3	19	42	39	32
4	14	68	43	14
5	3	81	8	0
6	7	139	19	0

FIGURE 1. Testing delay vs. average "C" value - the time period between taking a sample in the field and testing it in the laboratory.



Ops. number	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	9	115	65	11
2	6	79	16	0
3	4	71	39	0
4	11	69	16	0
5	6	43	19	33
6	5	36	8	40
7	49	36	47	49
8	2	107	8	0
9	2	93	61	0
10	2	72	4	0
11	1	56	-	0
12	1	35	-	0
13	2	21	46	50

FIGURE 2. Contractor operation vs. average "C" value.

It should be noted that all of the five operations with low mean "C" value (except #12) also have the highest percentage of failures ("C" value below 30). Also of interest is that operations #4, 5 and 7 do business under several different names; however, the operator/owner and plants were the same.

3. Plant Type

Specific asphalt plants were first separated by general type: either drum mixer or batch plant. The results are shown at the top of Figure 3. There is a significant difference (at the 90% level) between the two types, with the drum mixer having lower mean "C" value and a higher percentage of failures.

Next each specific plant was analyzed as to type and owner. The results are also shown in Figure 3. The contractor operation numbers from Figure 2 are listed along with a designation of plant type and dust collection method. Results from plants with one or two tests are shown with dashed lines.

Some drum mixer and batch plants show low average "C" values and a high percentage of failures. Drum mixer plants with potential problems are felt to be #4, 5, and batch plants #1, 2, 7 and 8 - the latter four based on limited data.

4. Dust Collection System

Two types of dust collection systems were investigated: wet scrubber and bag house. There were no cyclone plants in the sample, except where they were used in conjunction with wet scrubbers. The results are shown in Figure 4. These is a very significant difference

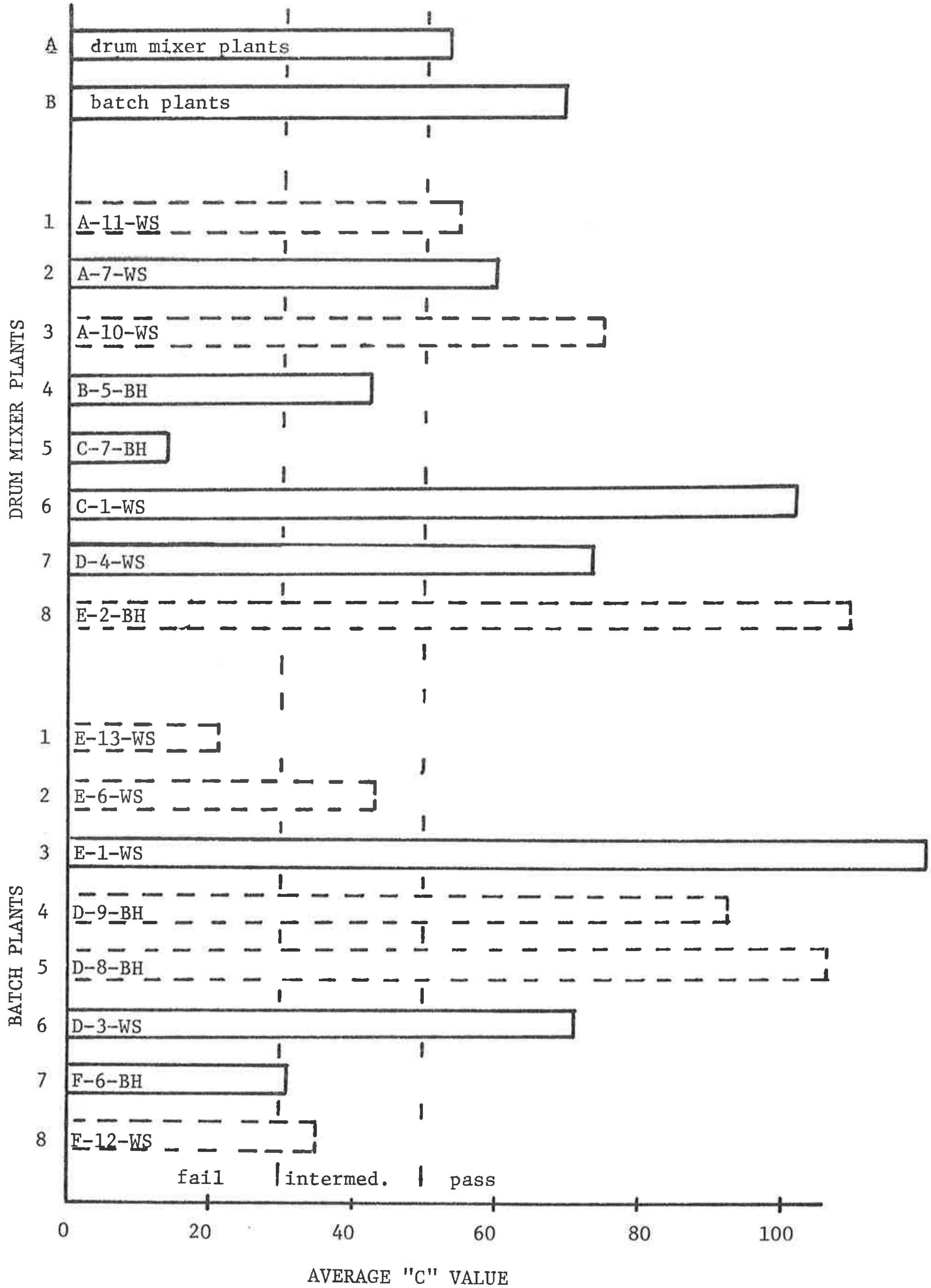
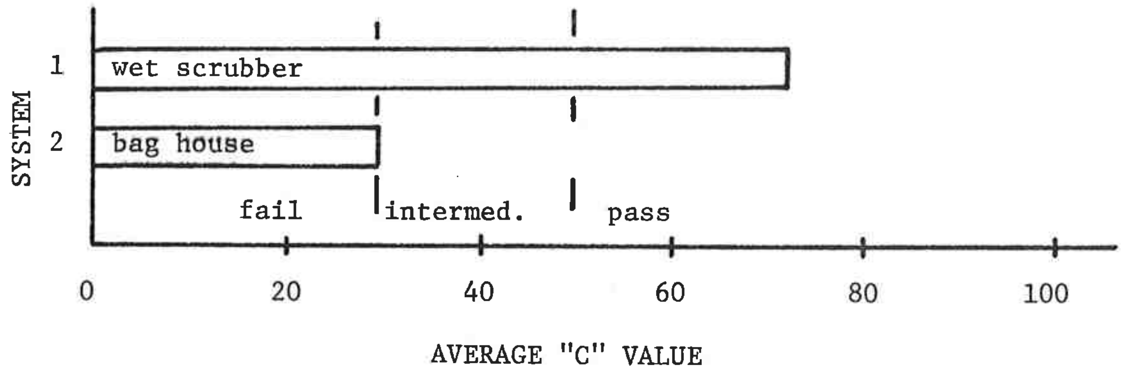


FIGURE 3. Asphalt plant type vs. average "C" value. Symbol meaning: A through F are plant manufactures, 1 through 13 are contractor operation (Fig. 2), and WS = wet scrubber, BH = bag house.

Plant type	Number of tests	Mean "C" value	Standard deviation	Percent failures
A	82	54	52	35
B	16	74	51	19
		Drum mixer plants		
1	1	56	-	0
2	19	61	46	26
3	2	72	4	0
4	6	43	19	50
5	28	14	30	75
6	7	103	70	14
7	16	70	14	0
8	1	111	-	0
		Batch plants		
1	2	21	46	50
2	2	44	2	0
3	3	122	59	0
4	2	93	61	0
5	2	107	8	0
6	4	71	39	0
7	3	31	6	67
8	1	35	-	0

FIGURE 3. continued. Asphalt plant type vs. average "C" value.



Dust system	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	54	72	44	9
2	42	30	40	62

FIGURE 4. Dust collection system vs. average "C" value.

between the two averages (at the 99.95% level), with the bag houses having the lower mean "C" value and most of the failures.

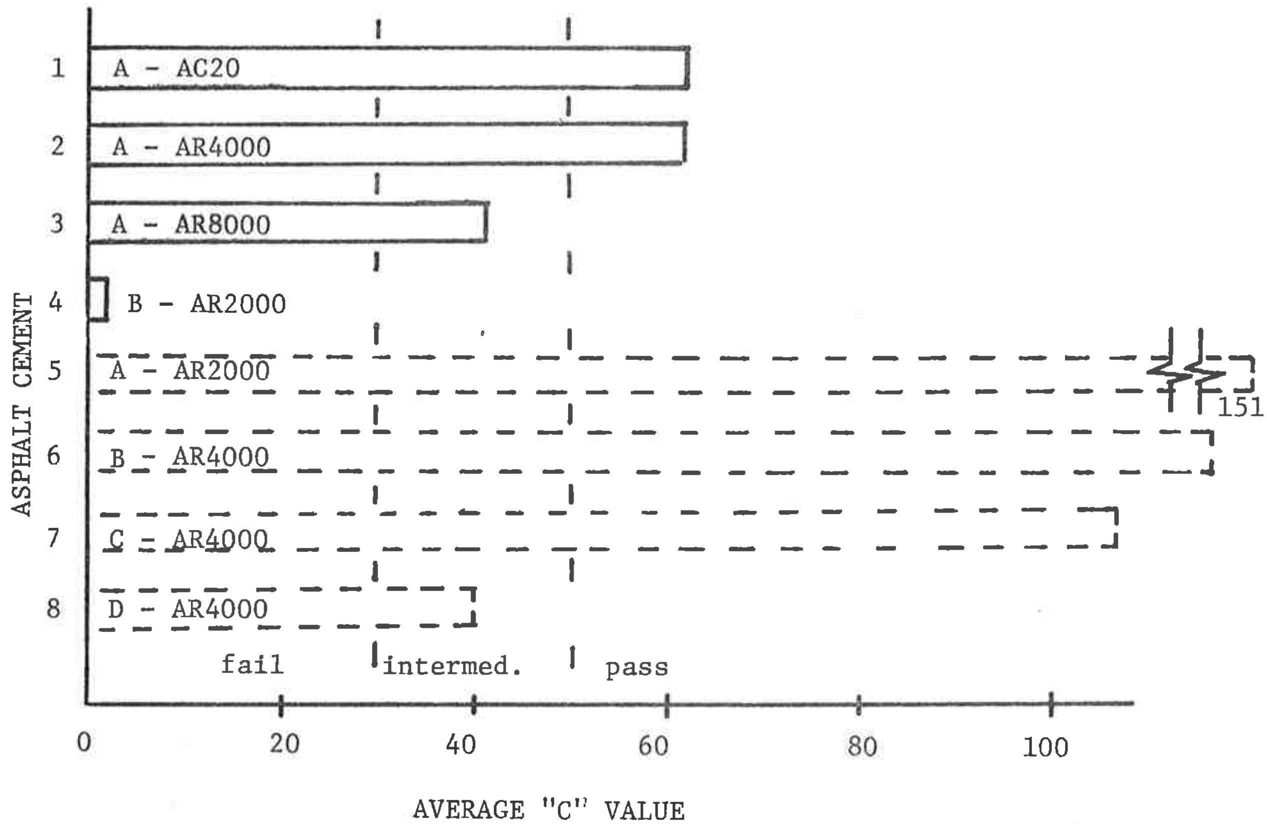
5. Asphalt Cement Grade and Supplier

Four different suppliers of asphalt cement (designated by letters A through D) were included in the analysis and are shown graphically in Figure 5. Of these, asphalt cement #4 (supplier B) was considerably below average and had a high number of failures, including negative values. This particular asphalt has a high temperature susceptibility, which may account for the unusual results. The results for asphalt cements #5 through #8 are shown with dashed lines since they are based on only one or two tests. The asphalts are graded by rolling thin film oven residue viscosity (AR) or original asphalt viscosity (AC) in the current asphalt cement specification (Ref: Oregon State Highway Division 1983 Specifications for Asphalt Materials).

6. Burner Fuel Type

The most common type of burner fuel used is No. 2 fuel oil (diesel); however, there is an increasing use of reclaimed lubricating oil, transformer oil or turpin oil to reduce cost. By using reclaimed fuel a contractor can save as much as $1.00 per ton of mix produced. Unfortunately reclaimed fuel can vary in composition and quality. As a result there is a greater potential for mix contamination since all of the fuel may not combust properly.

A third group of burner fuel used in dryers is natural gas and propane, which obviously do not leave significant residue.



Asphalt cement	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	4	62	15	0
2	66	62	42	30
3	3	41	21	33
4	16	2	39	56
5	1	151	-	0
6	2	117	51	0
7	2	107	8	0
8	2	40	23	50

FIGURE 5. Asphalt cement grade and supplier vs. average "C" value Letters A through D designate different suppliers.

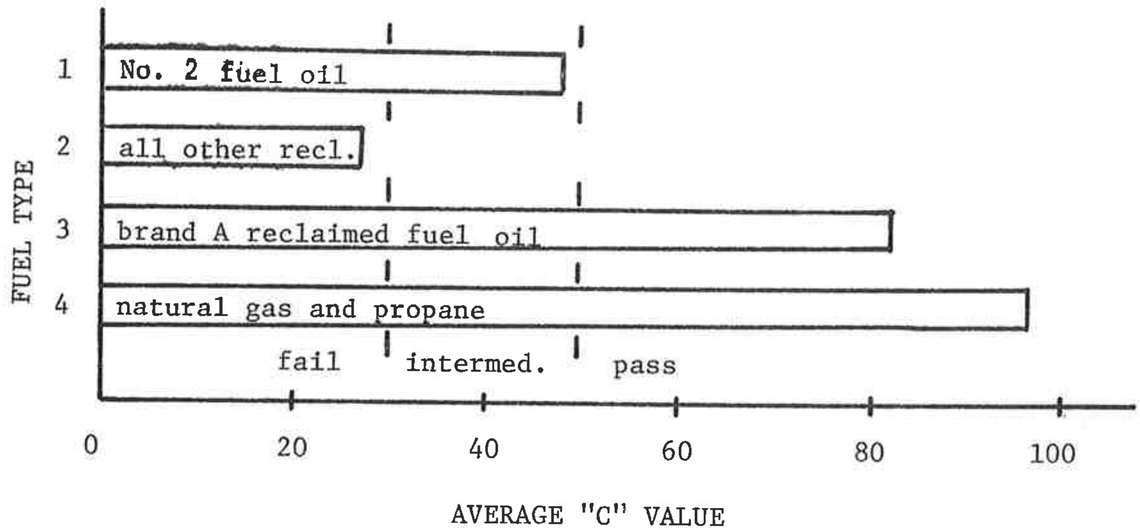
In analyzing the data for the reclaimed fuel oils, one specific brand could be identified (brand A), and since there were sufficient test results for this brand, it was separated from the remaining reclaimed fuel oils. As shown in Figure 6, the natural gas and propane samples along with brand A of the reclaimed fuel oils had a high mean "C" value and a low percentage of failures. The remaining reclaimed fuel oils had a low "C" value average and a high percentage of failures. The No. 2 fuel oil values fell in the middle of the above results.

7. Fuel Oil Specifications

When asphalt samples were taken during the 1983 season, a burner fuel oil sample was taken at the same time. These burner fuel oil samples were analyzed in the laboratory to determine if they met the No. 2 fuel oil specifications (ASTM D 396). The asphalt "C" values were then grouped according to whether the fuel oil sample passed or failed as shown in Figure 7. Even though the results show a slight difference in mean value, statistically there is no significant difference. All of the failures were due to samples having high specific gravity, high kinematic viscosity and high amounts of water and sediment.

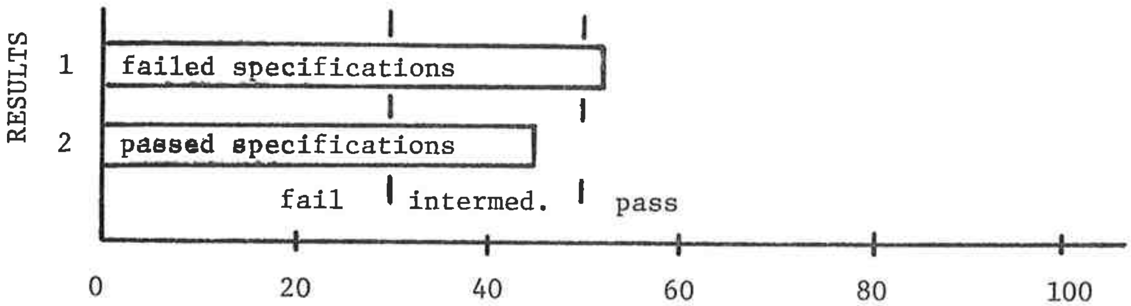
8. Asphalt Concrete Mix Class

The most common asphalt concrete mix used on highways in Oregon is the class-B mix, a 3/4-inch maximum sized, dense graded mixture, typically having around 5.5 percent asphalt by weight of mix. Data for two other mix classes were also available; class-C mix, a 1/2-inch maximum sized mix used mainly for urban streets; and a class-E mix, a 1/2-inch maximum sized mix used as an open graded friction course (see



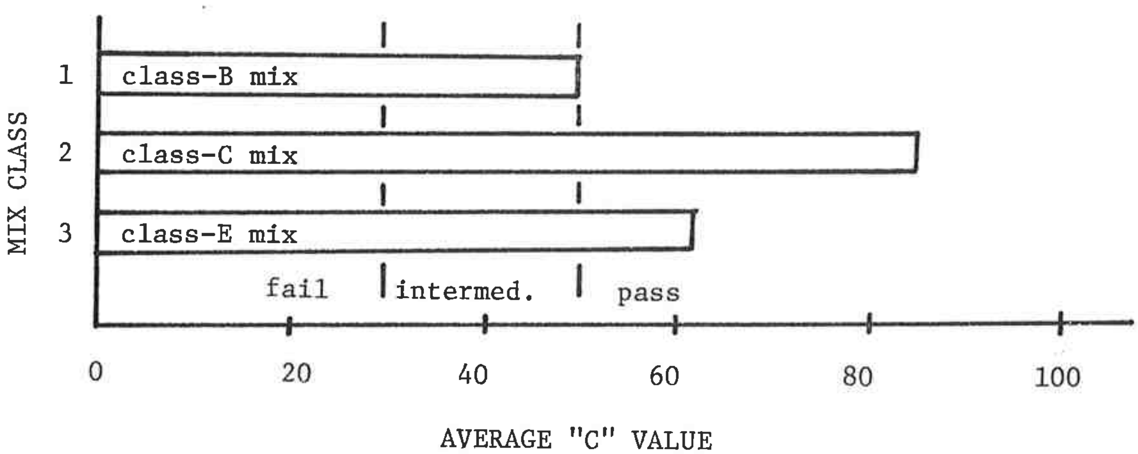
Fuel type	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	45	48	27	33
2	26	27	49	41
3	11	82	44	9
4	16	97	58	12

FIGURE 6. Burner fuel type vs. average "C" value.



Spec. results	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	8	52	38	50
2	35	45	33	43

FIGURE 7. Fuel oil specification vs. average "C" value. Specification based on No. 2 fuel oil (ASTM D 396).



Mix class	Number of tests	Mean "C" value	Standard deviation	Percent failures
1	86	50	46	34
2	8	85	56	25
3	4	62	15	0

FIGURE 8. Asphalt concrete mix class vs. average "C" value

OSHD Standard Specification 403.11 - 1974). The class-E mix is often used as an overlay over class-B or -C mixes. Temperature specifications require that the mixture be between 240 and 300°F at laydown for class-B and -C mixes and 200 to 250°F for class-E mix. The maximum mixing temperature for all classes is 325°F (see OSHD Special Provisions, 1983).

The results of grouping the "C" values according to mix class are shown in Figure 8. The class-C mix values have the highest mean "C" value and the class-E mix have no failures; however, the sample size is limited. The class-B mix results are close to the overall total sample results. The relationship between mix class and average "C" value do not appear to be a significant factor.

Burner Fuel Contamination

Burner fuel oil samples, original and reclaimed asphalt samples were also tested from two construction projects for contamination. The samples were submitted to Oregon State University for testing by gas chromatographic procedures (Miller, 1983). The first set of samples, tested in October of 1982, had a fuel oil sample that did not pass the No. 2 fuel oil specifications (ASTM D 396). This sample was a reclaimed fuel oil, failing the test due to high flash point (200°F) and high kinematic viscosity (31 cSt @ 100°F). It actually fit a No. 6 fuel oil specification. The gas chromatographic procedures indicated that the recovered asphalt had been contaminated with fuel oil (estimated at 8% by weight of asphalt). The average "C" value for the asphalt at that time was 22.6%. In the field, due to extreme tenderness of the mix, a section of new pavement had to be removed and replaced.

The second set of samples, tested in May of 1983, had fuel oil samples (4) that did pass the No. 2 fuel oil specifications. The recovered asphalt showed no indication of fuel oil contamination as determined by the gas chromatographic procedures. In addition, 100% of the fuel oil would volatilize whereas only 43% of the October, 1982 sample would volatilize. The original asphalt was essentially the same for both test dates. The average "C" value for the May, 1983 samples was 29.7%. There were indications that the mix temperature was low during the May, 1983 sampling, probably accounting for the low "C" values.

SUMMARY AND DISCUSSION

Summary

The data presented in the Results section indicated that a number of items directly or indirectly contributed to the tenderness problem. Asphalt mixing plant design, type of dryer, dust collection system, asphalt grade and supplier, and burner fuel type all appear to be related to this problem. Other items that had limited measurements but which can contribute to the problem and are probably related to items listed above are mix moisture content and mixing temperature.

In order to have a better overview of the causes of tenderness, two summary tables have been prepared. The first relates contractor operation as was shown in Figure 2 to various items that had low average "C" values. In addition, based on limited field observations (some projects were not completed at the time this report was prepared), those pavements with tenderness problems were also identified. Table 1 presents this summary. Three operations stand out by having four or more problem areas checked.

Table 2 presents a similar list of problem items as related to specific asphalt plants as previously listed in Figure 3. Two of the drum mixer plants have more than four areas checked and two of the batch plants have three areas checked. All but one of the plants (batch plant #1) are part of the three problem operations listed in Table 1. Batch plant #1 results are only based on two test samples, thus the results are probably questionable.

Discussion

The tenderness problem, as measured by the "C" value, appears to be the result of one or several interrelated conditions. These are:

1. type of burner fuel used and its combustion,
2. temperature of the mixing operation,
3. oxidation rate during mixing (the efficiency of the mixer), and
4. the origin and grade of asphalt.

The use of reclaimed fuel has a critical affect on the operation. Contaminated and heavy oils do not combust as efficiently as clean-light oils, thus the potential for contamination is present. The unburned residual fuel oil will coat the aggregate and asphalt causing the asphalt to liquify and behave as a softer grade or slow setting asphalt. Even with "good" fuel oil, a low mixing temperature can cause incomplete combustion and leave a residual coating. This was demonstrated in the California study mentioned earlier (Apostolos, et. al., 1974).

Contractor Operation #	Pavement with reported problem	Drum mix plant used	Batch or drum mix plant with low "C" value	Batch or drum mix plant with bag house	Asphalt cement used with low "C" value	Plant using reclaimed fuel	High percentage of failing "C" values	High number of potential problems
1	x	x						
2		x				x		
3	x							
4		x						
5	x	x	x	x		x	x	***
6			x	x	x		x	***
7	x	x	x	x	x	x	x	***
8				x				
9				x				
10		x						
11		x						
12			x					
13					x		x	

TABLE 1. Summary of contractor operation characteristics. (see Fig. 2).

Plant #	Plant with low "C" values	Plant using bag house	Asphalt cement used with low "C" values	Plant using reclaimed fuel	Pavements with reported problems	High percentage of failing "C" values	High number of potential problems
			drum mix plants				
1							
2			x	x			
3							
4	x	x		x	x	x	***
5	x	x	x	x	x	x	***
6					x?		
7				x			
8		x					
			batch plants				
1	x		x			x	***
2	x		x				
3					x		
4		x					
5		x					
6					x		
7	x	x				x	***
8	x						

TABLE 2. Summary of asphalt plant characteristics (see Fig. 3).

Unfortunately, the temperature during mixing and paving was not recorded for each sample. However, for one project, a number of samples were taken while the temperature of the mix was raised. In this case the "C" value approximately doubled when the mix temperature at the plant was raised from around 290°F to 325°F. When the burner fuel was changed to propane, and the temperature kept the same, the "C" value did increase, but not as much. Thus mixing temperature can have a very significant effect on the viscosity of the inplace asphalt.

In one series of laboratory RTFC tests the asphalt hardened (viscosity increased) 3.75 times more when raising the temperature of the test from 250 to 325°F when compared to the original asphalt viscosity at 140°F (Petroleum Sciences, Inc., 1983).

The oxidation rate or the efficiency of the mixer is related to the temperature and fuel combustion problem discussed above. Other items that affect the amount of asphalt hardening are the construction and operation of the mixer. This is especially true in drum mixer plants. The oxidation rates appear more variable in drum mixers as compared to batch plants. The location of the burner flame nozzle, the asphalt input location and the mix retention time are all critical. In addition the use of a bag house dust collector can also reduce the oxidation process. Some contractors are reluctant to raise the burner temperature for fear of scorching and/or burning the bags. Baffle construction and wear in the drum can also affect the efficiency. In one plant, where the drum baffles were worn, the mix was only rotated and dropped through a portion of the drum opening while the majority of the burner flame was bypassing through the other portion of the opening, obviously not an efficient process. Finally, excessively wet aggregate can prevent adequate oxidation, especially at low temperature.

In general, the source and grade of asphalt should not affect the "C" value test results. The exception appears to be on a project when asphalt #4 (supplier B) in Figure 5 was used. This AR 2000 asphalt is harder than other brands at low temperature and softer at high temperatures. In addition the viscosity change from original to RTFC is about half of other asphalts. Thus at high pavement temperatures the asphalt would be more fluid and thus behave initially as a tender mix. This problem has been observed in the field. However, other contributing factors could be involved. Possibly this high temperature susceptibility may contribute to the low "C" values. The long-term performance of pavement constructed with this asphalt appears to be good.

A more detailed discussion of penetration/viscosity relationship and dryer-drum problems in Oregon can be found in Wilson and Hicks, (AAPT 1979). Many of the same problems identified in that study have also been encountered in this study.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of this study, although not completely conclusive, indicate that:

1. The "C" value is a good measure of aging (hardening) in the asphalt mixing and laydown process. "C" values below 30 will predict tenderness in the new pavement, thus helping to

prevent rutting, flushing, stripping, ravelling and segregation.

2. The selection of burner fuel type is critical in producing a satisfactory mix. Some lower grade fuel oils, due to poor combustion, will cause contamination of the mix by softening the asphalt.

3. Low temperature in the mixing or aggregate drying process, especially in drum mixer burners, is detrimental to the mix. This will produce less aging and poor combustion of burner fuel oil.

4. The overall operation and construction of asphalt plants, especially as related to items 2 and 3 above and the use of bag house dust collectors, has a significant influence on the tenderness of the produced mix.

Recommendations

The results of this study have led to the following recommendations being adopted by the Oregon Department of Transportation (specification 403.39 as given in Appendix A):

1. Burner fuel approved for most projects should consist of natural gas, liquified natural gas, fuel oil (ASTM D 396, Grades No. 1 and No. 2), butane, propane, and other that may be approved upon acceptable testing.

2. Burner fuel combustion will be considered complete and/or acceptable aging of the asphalt attained when the "C" value (percent of change in asphalt viscosity) is equal to or greater than 30.

ACKNOWLEDGMENTS

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DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those held by Oregon Department of Transportation or Oregon Institute of Technology.

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APPENDIX A

Oregon State Highway Division
Special Provision

<u>403.39 Drying, Heating and Separating Aggregates into Designated Sizes</u> - Delete the provisions of this subsection of the Standard Specifications and substitute the following:

The requirements of subsection 401.39 shall apply except that the last two paragraphs are not applicable to bituminous mixing plants without screens.

The burner fuel used for heating the aggregates shall be of approved by the engineer. On this project, only the following burner fuels have been approved:

1. Natural gas
2. Liquified natural gas
3. Fuel oil: (ASTM D 396, Grades No. 1 and No. 2)
4. Butane
5. Propane

The burner used for heating the aggregates shall achieve complete combustion of the approved fuel and shall heat the aggregates sufficiently to achieve acceptable aging of the asphalt. Burner fuel combustion will be considered complete and/or acceptable aging of the asphalt attained, when "C" (percent of change in asphalt viscosity) in the following formula is equal to or greater than 30:

$$C = \frac{R-A}{B-A} \times 100 \text{ where;}$$

A = Absolute viscosity (OSHD TM 417) of original asphalt used in production of the mixture.

B = Absolute viscosity (OSHD TM 417) of rolling thin film oven residue (AASHTO T 240) for asphalt used in production of the mixture.

R = Absolute viscosity (OSHD TM 417) of asphalt from the mixture (OSHD Modified AASHTO T 170).

Testing to determine "C" will be made whenever the engineer believes complete combustion of the approved fuel may not be occurring. Whenever "C" is less than 30, the contractor shall stop production and make appropriate adjustments to comply with this requirement before resuming production. Any mixture represented by such tests which has been placed shall be rejected and shall be removed and disposed of by the contractor entirely at his expense and in a manner acceptable to the engineer. After production has resumed the engineer will retest the asphalt and mixture for compliance.

When test results indicate "C" to be less than 30, and when retesting is performed as set forth above, the cost of said tests shall be borne by the contractor. Current charges for each complete test to determine "C" can be obtained from the engineer.

Burner fuels not in the above list may be approved by the engineer upon written request of a contractor or supplier. Prior to approval, testing will be done on asphalt concrete samples taken from a plant using the fuel to determine "C" as described above. The asphalt concrete mixture samples to be tested shall be submitted to the engineer at least 10 days prior to the planned use of the fuel on any Highway Division contract. Two complete tests will be run. The fuel may be approved for use if the average "C" value from the two tests is equal to or greater than 30. All testing costs shall be borne by the contractor or supplier.

For screen-type plants the temperature of the aggregates at discharge from the dryer shall not exceed 325°F unless used for heat transfer medium in batch type plants. For drum mix plants the temperature of the mix at discharge from the mixer shall not exceed 325°F.