The Correlation between Mixture Distress and Strength of Bituminous Concretes

Kim, Kwang Woo
Department of Agricultural Engineering, Kangweon National University

Abstract ☐ Many distress mechanisms in pavement are known to be caused by the poor mechanical properties of bituminous concretes. Among many mechanical properties, tensile strength is one of the more important indicates that represent the resistance of pavement to traffic loading. However, there has been no relationship established between the strength and distress mechanisms. Therefore, this study was conducted to evaluate a correlation between the tensile strength value and the intensity of distress in bituminous concrete.

Distress data were collected from an extensive field investigation over 77km of a four-lane highway in South Carolina, USA, and from laboratory prepared specimens in two phases of study. Strength data were obtained from a total of more than 400 field cores taken from the same highway and from 640marshall specimens of surface course mixture prepared in the laboratory. These data were analyzed using statistical test techniques.

It was found from statistical analyses that the tensile strength of bituminous concrete had a strong relation with the pavement condition in the field. In the analysis of rutting and stripping, low strength concrete showed a higher distress rate in the mixture, and mixtures under distress in the field showed obviously reduced strength values. Stripping was found to be the most significant distress mechanism that was correlated with low strength bituminous concrete. Rutting appeared more frequently in a low strength pavement section of the highway as a sign of failure due to traffic loading.

Keywords ☐ Bituminous Concrete, Tensile Strength, Distress, Marshall Specimen, Asphalt, Surface Course, Pavement, Rutting, Visual Stripping Rating,

I. INTRODUCTION

1. Statement of problems

The performance of bituminous concrete in pavement depends on many factors. These factors can be broadly divided into several groups ; the design and construction, the external causes, and properties of the pavement mixture, etc. Even though many pavement distresses are induced due to the unsuitable design and construction, and/or external causes, (e.g., excessive traffic loading and severe weather conditions), the mixture property itself is also one of the most important reasons.

Many distress mechanisms in pavements are correlated with the poor mechanical properties in the pavement mixture. Among many mechanical properties,the tensile strength of the mixture is one of the more important factors for the pavement to perform properly. If the relationship between any one of the pavement distresses and the tensile strength is known, estimating the distress level based on the strength may be possible. However, there has been no relationship established between the intensity of the distress and the strength level of pavement mixture. Therefore, the overall objective of this study is to examine the relationship between the tensile strength and the mixture distress of asphaltic concrete mixture.

2. Preparation of field and laboratory data.

A field investigation of flexible pavement was conducted on I-85 and I-95 in S.Carolina, U.S.A. Surface rutting and mixture stripping, the most distinct distresses in this area, were investigated. Wet coring was conducted on I-85 for an investigation of the pavement mixture condition. A 10-cm-diameter (4-inch) core was obtained for every half mile of each lane. A total of more than 400 cores were taken from 77km of four-lane highway. Tensile strengths of the pavement surface course were measured on cored specimens using an indirect tensile strength (ITS) test technique at 25℃ (1).

Based on the standard specifications of the south carolina departement of highways and public transporation(8), type 3 surface mixtures were prepared in the laboratory with three aggregates and four AC-20 asphalt cements. A total of 640 marshall specimens were made and tested to examine a correlation between tensile strength and mixture stripping.

These field and laboratory mixtures were statistically analyzed to find correlations between the tensile strength, and the surface rutting and mixture stripping. The tensile strength value was used as the dependent variable and the rate of rutting and visual stripping were used for the independent variables.

II. INVESTIGATION OF DISTRESSES OF FIELD MIXTURE

1. Surface rutting

A rut is a surface depression in the wheel path. Pavement uplift may occur along the sides of the rut. Rutting may be caused by plastic movement in the mix during hot weather, or inadequate compaction during construction. This deformation causes a loss of strength in the mixture, leading to major structural failure of the pavement (5). Significant rutting can also lead to a hydro-planing potential (7).

Surface rutting of the pavement in each lane was investigated throughout the coring section of the highway. At each site, rut depths of the surface were measured at inside and outside wheel paths before taking a core. The depths of the rutting on the surface ranged from 0cm to over 3.2cm. The range of rut depth was divided into six groups (from 1 to 6) and used in statistical analysis, as shown in Table 1. Tensile strengths of the cored mixtures were investigated based on the surface rut depth. In general, the average tensile strength decreased as the surface rutting increased. For example, the average tensile strength at sites that were free from rutting was over 470kpa (Table 1). For the mixtures from the medium-severity-level rutting (1.27-2.54cm), the average strength was below 350kpa.

Table 1. Relation of Tensile Strength and Rutting for Field Mixture

Tensile Strength (kPa)	Rutting 1	2	3	4	5	6
Mean	472.3	394.4	369.6	356.5	–	312.3
Standard Dev.	194.4	164.8	131.0	117.0	–	82.7

Legend for Rutting:

1: rut depth=0cm

2: 0<rut depth<0.6cm

3: 0.6<rut depth<1.27cm

4: 1.27<rut depth<1.9cm

5: 1.9<rut depth<2.54cm

6: rut depth>2.54cm

2. Stripping of asphaltic concrete mixtures.

Stripping involves the detachment of asphalt cement film from the surface of the aggregate to which it should adhere. As asphaltic concrete loses cohesive bonding, the mixture is weakened and the fatigue life of the asphaltic concrete is reduced. Since pavement layers in which stripping has occurred do not perform satisfactorily, stripping causes premature loss of serviceability, increased liability for maintenance forces and increased cost for rehabilitation or reconstruction (2, 3, 9). The stripped pavement may exhibit evidence of surface distresses such as spot flushing, rutting, ravelling, plastic deformation, roughness, and premature deterioration.

Stripping may be due to high annual rainfall, the high ambient humidity (which prevents rapid drying), and year-round distribution of rainfall and moisture (2). Although there are many factors that have an effect on stripping, moisture may be the element that is most often responsible for the weakening that causes stripping (9).

Following the tensile strength test on each specimen, the surface condition of the exposed aggregates on broken faces was examined. A visual rating of the stripping that occured in the exposed crossed-section was made by estimating the percentage of the stripped fine aggregate matrix and the coarse aggregate fraction to total aggregates. Since the percentage estimation in this method is made visually, this procedure requires training for consistent interpretation of results. Visual stripping rating (VSR) values were divided into five groups (A through E) and used in statistical analysis, as shown in Table 2. Stripped mixtures generally produced lower tensile strength than undamaged ones. Also mixtures obtained from a severely rutted area showed relatively high stripping ratings.

Table 2. Relation of Tensile Strength and Stripping for Field Mixture

Tensile Strength (kPa)	Visual Stripping Rating				
	A	B	C	D	E
Mean	449.6	384.1	349.6	344.1	337.2
Standard Dev.	196.5	108.3	122.0	92.4	110.3

Legend for VSR
A: almost no stripping
B: 0%<stripping<10%
C: 10%<stripping<25%
D: 25%<stripping<40%
E: Stripping>40%

III. CORRELATION OF RUTTING, STRIPPING AND TENSILE STRENGTH FOR FIELD MIXTURES

1. General linear model procedure

The relationships of the rutting and visual stripping rating with the tensile strength values were statistically analyzed using the statistical analysis system (SAS) (4, 6). The general linear model (GLM) procedure was chosen for analysis of variance because data sets (sample numbers for rutting and stripping) were unbalanced (6). Tensile strength values were used as the dependent variable for analysis. F-tests were conducted in the analyses of variances with six ruttings and five VSRs. Mean values for tensile strength in various conditions were compared using the least square difference (LSD) method.

2. Results of statistical analysis

The results of the analyses, shown in Tables 1 through 4 and Figure 1, revealed that tensile strength values generally decreased as rutting or stripping increased. Tensile strength values for the stripped mixtures were significantly lower (at $\alpha=0.01$) than the tensile strength values from stripping-free mixtures. Even though rutting did not show any significance among its means in the statistical test (Table 4) at $\alpha=0.05$, a pattern that tensile strength decreases as rut depth increases is noticeable in Tables 1 and 3. According to the results of GLM analysis in Table 4, a significant correlation was also found at, $\alpha=0.05$, between rutting and stripping (interaction term between VSR and rutting in Table 4). From this result, it could be noticed that severe stripping contributed to increased rutting.

The average tensile strength value for mixtures that were free from both stripping and rutting was over 580kpa. However, the average tensile strength for mixtures that were stripped and rutted, for example, VSR=C and rutting=3, was approximately 350kpa(Table 3). Most of the tensile strength values for mixtures from nearly distress free conditions(rut=0.6cm and VSR=A) were above 450kpa. Average tensile strength values of the specimens from areas of relatively less severely distressed conditions were over 400kpa (for example, rutting=3 and VSR =A, rutting=1 and VSR=B, in Table 3). Otherwise, almost all average tensile strength values from distressed conditions were below 400kpa, and many were below 350kpa.

Table 3. Mean Tensile Strength Values based on Rutting and VSR for Field Mixtures

Rutting	Visual Stripping Rating				
	A	B	C	D	E
1	583.3	406.1	—	—	—
2	462.7	400.2	356.5	333.7	324.1
3	406.1	335.8	345.4	361.9	263.4
4	390.3	—	—	329.6	—
5	—	—	—	—	—
6	325.4	—	305.4	—	—

Legend for Rutting:
1: rut depth=0cm
2: 0<rut depth<0.6cm
3: 0.6<rut depth<1.27cm
4: 1.27<rut depth<1.9cm
5: 1.9<rut depth<2.54cm
6: rut depth>2.54cm

Legend for VSR
A: almost no stripping
B: 0%<stripping<10%
C: 10%<stripping<25%
D: 25%<stripping<40%
E: Stripping>40%

Table 4. Analysis of Variance for Stripping and Rutting with Tensile Strength (kPa) as Dependent Variable

SOURCE	DF	SUM OF SQUARES	F VALUE	PR>F
RUTTING	5	3040.46	1.75	0.1224
VSR	4	7632.45	5.49	0.0003**
VSR*RUTTING	14	9258.81	1.90	0.0250*
ERROR	341	118429.01		
CORRECTED TOTAL	364	138429.99		

*Significant at $\alpha=0.05$, **Significant at $\alpha=0.01$

According to smith, et al. (7) and APWA (5), a rut depth of less than 0.6cm (rutting=2) is minor distress, and according to the Georgia DOT method, stripping of less than 10% in coarse or fine aggregates (VSR=B) is regarded as minor stripping. Average tensile strength values for these minor rutting and stripping conditions can be obtained from Table 3. The approximate value of tensile strength satisfying this condition was above 400kpa. However, according to the mean value in Table 2, there was a large difference between mean strengths for VSR=A and VSR=B. In other words, even minor stripping (VSR=B) cuased a singificant reduction of tensile strength in the field mixtures.

IV. RELATION OF STRIPPING WITH TENSILE STRENGTH FOR LABORATORY PREPARED MIXTURES

For field mixtures, it was shown that rutting and stripping had correlations to the reduction of the mixture strength. For mixtures prepared in the laboratory, the relation between the mixture stripping and the mixture strength was examined. Since rutting could not be measured on the laboratory specimens, only stripping and tensile strengths were measured using the same method used for field mixtures.

Specimens prepared as explained in the introdction were randomly divided into two groups for dry and wet conditioning. The indirect tensile strength test for wet specimens was conducted using the Trunicliff and Root procedure (9) following 24 hours of soaking in water at a temperature of 60℃. The ITS test for dry-conditioned specimens was conducted following 4 hours of dry conditioning at 25℃. The mixture strength for stripping A was over 450kpa on the average for the total mixture and the average value decreased as stripping increased, as shown in Table 5. Individually, mixtures with asphalt III and IV showed higher strengths, and mixtures with asphalt I and II showed relatively lower strength (Figure 2).

Table 5. Relation of Tensile Strength and Stripping for Laboratory Prepared Mixtures

Tensile Strength (kPa)	Visual Stripping Rating				
	A	B	C	D	E
Mean	458.5	398.5	413.7	358.5	337.9
Standard Dev.	49.0	71.7	46.9	49.6	78.6

Legend for VSR

A: almost no stripping
B: 0%<stripping<10%
C: 10%<stripping<25%
D: 25%<stripping<40%
E: Stripping>40%

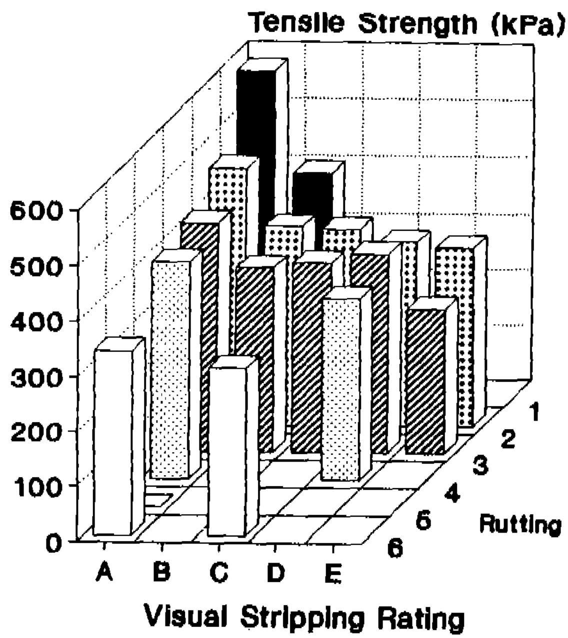

Figure 1. Tensile Strength based on Stripping and Rutting for Field Data

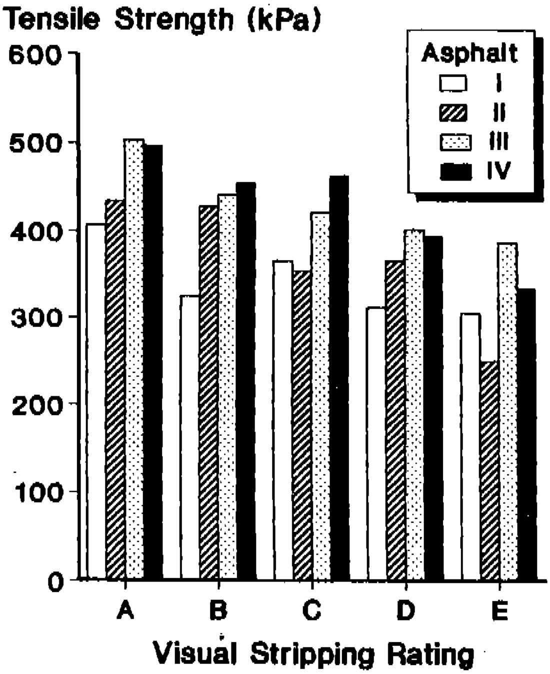

Figure 2. Tensile Strength Based on Stripping and Rutting for Laboratory Data.

Since the data were not balanced in terms of stripping, the GLM procedure was used for analysis of variance. The analysis of variance table (Table 6) shows significant differences of tensile strength among stripping ratings, aggregates, asphalts and VSR-aggregates. There was no significance found for VSR-asphalt, asphalt-aggregate and VSR-asphalt-aggregate interactions. This means that stripping is not correlated with asphalt type. However, since average strengths among stripping ratings were significantly different, strength reduction by the increasing intensity of stripping was also evident for laboratory prepared mixtures. Figure 2 shows the strength change of the asphalt mixtures by intensity of stripping and by asphalts (I through IV). In general, the laboratory mixture showed relatively higher strength with smaller deviation than the field mixture, as shown in Figure 3, Tables 2 and 5.

Table 6. Analysis of Variance for Stripping, Aggregates and Asphalts with Tensile Strength (kPa) as Dependent Variable

SOURCE	DF	SUM OF SQUARES	F VALUE	Pr>F
ASPHALT	3	30292.93	3.13	0.0266*
AGGREGATE	2	125634.90	19.45	0.0001**
ASPHALT*AGGREGATE	6	33416.06	1.72	0.1163
VSR	4	107915.43	8.35	0.0001**
ASPHALT*VSR	10	17372.19	0.54	0.8622
AGGREGATE*VSR	3	40642.54	4.19	0.0065**
ASPHALT*VSR*AGG.	5	30972.24	1.92	0.0923
ERROR	606	729922.98		
CORRECTED TOTAL	639	1464602.50		

*Significant at $\alpha=0.05$, **Significant at $\alpha=0.01$

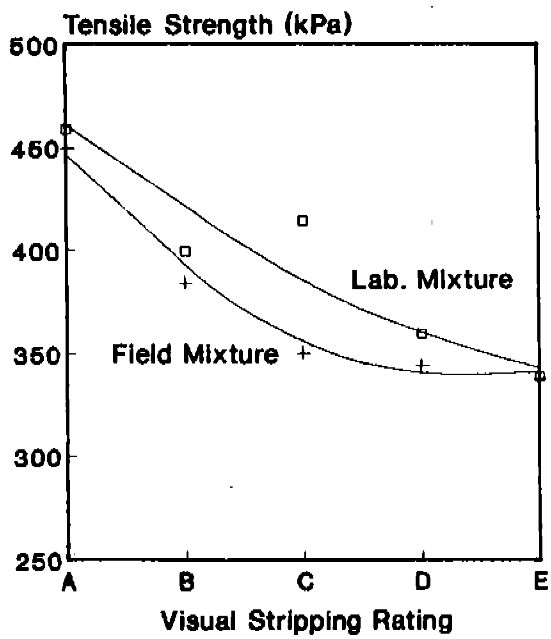

Figure 3. Difference of Mean Tensile Strength between Laboratory and Field Data.

V. EVALUATION OF TENSILE STRENGTH, STRIPPING AND RUTTING

1. Tensile strength based on stripping and rutting

Distress in the mixture obviously reduces the strength of pavement as shown previously in the analyses of rutting and stripping. The strength of the mixture with an acceptable level of distress could be obtained from those analyses ; for example, strength values of field and laboratory mixtures with a stripping of less than B.

It was found that a tensile strength of approximately 390 kpa or higher satisfied this condition. The value of 390 kpa also satisfied the minor condition of rutting (less than 0.6cm) in the field mixture. Therefore, a tensile strength of approximately 390 kpa for field mixtures seemed to be needed to maintain an acceptable rutting and stripping level for this section of highway.

Consider the correlation of stripping and rutting for field mixtures in terms of strength. Reduction in the tensile strength of the surface course to below 450kpa came when the rut depth increased from 0.6 to 1.27cm, with almost no stripping in the mixture (Table 3). Tensile strength was most sharply reduced in the area between VSR=A and VSR=B and Rutting=1 and Rutting=3, as shown in Figure 1, which was drawn to show a tensile strength based on visual stripping and rutting.

2. Relationship of tensile strength, stripping and rutting

Stripping is known to be induced primarily by presence of moisture, not by traffic loading (2). Once stripping occurs in field mixture due to the presence of moisture, traffic, with its random repeated loading, seems to contribute to deterioration of the bonding force between aggregates and asphalt cement. This will be one of the reasons why tensile strength of the field mixture is, in general, lower than that of the laboratoty mixture.

The relationship between the tensile strength of the mixture and these mixture distresses can therefore be interpreted in the following ways. First, stripping in the highway pavement mixture is induced by severe environmental factors, such as, high temperature and humidity of the air, in addition to the traffic loading. Then. the stripping process is accelerated as the severity of the factors increases over time, thereby reducing mixture strength. Second, since all the strippings C, D and E (higher stripping ratings) were obtained from mixtures under a rut depth of 0.6cm or more (more than minor rutting), stripped mixtures seemed to be more prone to rutting. In other words, the mixture strength of which is weakened due to stripping seems to be more prone to rutting, compared with other mixtures. Therefore, it can be assumed that, if the strength of the mixture is stronger, the pavement will sustain well against rutting for a longer period of time under the same environment.

VI. FINDINGS AND CONCLUSION

It was found from the statistical analyses that pavement's tensile strength was related with two pavement distresses in the field. Mixtures cored under surface rutting showed a significantly low tensile strength. Stripping for both field and laboratory mixtures was a significant distress mechanisms that was strongly correlated with low strength pavements. Mixture stripping and rutting showed a significant correlation between each other in terms of tensile strength.

It is not known whether a low strength mixture gets stripped more easily than a high strength mixture under the same moisture conditions. However, it seems obvious that the mixture loses its strength due to stripping. Once the mixture loses its strength, it fails to resist against the traffic loading, and then rutting on the surface begins to progress as a sign of failure. This was evidenced by the fact that all the severe stripping was detected from mixtures under more than minor rutting. The rutting is then followed by deterioration of the surface at an accelerated rate due to repeated loadding of traffic.

Since a significant correlation was found between mixture tensile strength and distress, a minimum level of tensile strength for the pavement to perform properly can be drawn based on acceptable mixture distresses (rut depth less than 0.6cm and VSR less than B). Since rutting and stripping were correlated to each other, an acceptable stripping can be estimated based on the significance of rutting. The strength of the surface course would be below the minimum level in this highway if the pavement shows more than a minor depth of rutting on the surface, or if a visual stripping rating for the mixture cored from a site is greater than B.

The results and conclusions drawn in this study are based on the pavement data collected. However, the procedures and methodology that are present in this paper can be used to find a correlation for any other pavement data. Further study will be possible to suggest mathematical equations for strength prediction based on distress levels if distress can be interpreted as numerical values.

REFERENCES

1. Burati, J. L. and Kim, K. W., "Coring of I-85", Clemson University Final Report Submitted to South Carolina Dept. of Highway and Public Transportation, October 1986.
2. Busching, H. W., Burati, J. L. and Amirkhanian, S. N., "An Investigation of Stripping in Asphaltic Concrete in South Carolina", Department of Civil Engineering, Clemson University Final Report Submitted to FHWA, Report No. FHWA-SC-86-02, July 1986.
3. Kennedy, T. W., Roberts, F. L. and Anagnos, J. L., "Texas Boiling Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," Research Report 252-5, Center for Transportation Research, the University of Texas, Austin, Texas, January 1984.
4. Mendenhall, W., Introduction to linear models and the design and analysis of experiments, Duxbury press, Belmont, CA, 1968.
5. Pavement condition Index, Field manual, Asphalt, American public works association, 1981.
6. SAS user's guide: Statistics, 1987 edition, SAS Institute, Inc., Cary, NC, 1987
7. Smith, R. E., Darter, M. I. and Herrin, S. M., "Highway Pavement Distress Identification Manual", Interim report 1977-1979, FHWA, U.S. Dept. of Transportation, Washington, D. C., 1979.
8. Standard Specification for Highway Construction, South Carolina Department of Highways and Public Transportation, 1985.
9. Tunnicliff, D. G. and Root, R. E., "Use of Antistripping Additives in Asphaltic Concrete Mixtures-Laboratory Phase", National Cooperative Highway Research Program Report 274, Transportation Research Board, National Research Council, Washington D.C., Dec, 1984.