Characterization of Resistance to Aggregate Degradation and Rutting of Asphalt Mixtures

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by

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Thesis Certificate

This is to certify that the thesis titled **Characterization of Resistance to Aggregate Degradation and Rutting of Asphalt Mixtures**, submitted by **Priyansh Singh**, to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a bona fide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Abstract

Under vehicular loading, stresses are induced in flexible pavement. This induced stress results in strain in individual pavement layers. If the applied stress is within linear viscoelastic limits, then complete recovery of induced strain takes place. With increase in magnitude of loading and/or number of repetitions, this recoverable property of pavement material decreases and can lead to some permanent strain. The accumulation of this permanent strain from all pavement layers results in surface deformation. This is commonly referred to as rutting. Rutting causes the distortion and loss of surface smoothness as well as reduction in the load carrying capacity of the pavement. The overall objective of this study was to understand some issues related to asphalt concrete (AC) behavior with reference to rutting through a combination of laboratory investigation and analytical approach. Specifically this thesis addressed issues related to (1) degradation of aggregate during impact compaction, (2) interrelationship between binder and mixture properties related to rutting, and (3) development of probabilistic framework for rutting test results at laboratory scale.

In this research, five distinct aggregate blends were evaluated. This includes (i) two aggregate gradation as per Indian specification, (ii) two aggregate gradation as per Bailey mixture design approach and (iii) one gap-graded aggregate gradation specific to stone mastic asphalt (SMA) mixture. Further, one unmodified binder and two modified binders (polymer modified and crumb rubber modified) were used in this study. Using these aggregate blends and binders, nine asphalt concrete mixtures were designed and evaluated.

In order to deliver best mechanical performance, loose AC mixture is required to be compacted to optimal condition. The compaction process improves the material density by changing the aggregate skeleton while reducing the air voids. During the compaction process, some aggregate particles breakdown due to (1) the impact loading and (2) abrasion. This disintegration will affect the final aggregate gradation and consequent volumetric properties of

AC mixture. Among all compaction methods, impact method of compaction (used with Marshall mix design) is more susceptible to this type of aggregate degradation. In this study, the effect of compaction on aggregate degradation and consequent volumetrics using Marshall compactor is studied. In total, nine different mixtures were designed using Marshall mixture design method. The designed mixtures were compacted to produce Marshall specimens (4 inch and 6 inch diameter) at four different levels of compaction using standard and modified Marshall compactor. The aggregates from the compacted specimen were recovered and regraded to examine the changes in aggregate gradation. The results indicate that the aggregate degradation is a systemic process. The results indicate that the compaction level, aggregate type, and size of specimen significantly affect the degradation of aggregates. The study also shows that the aggregate degradation affects the VMA of the mixtures significantly. Several empirical parameters relating aggregate degradation with associated variables are proposed in this research.

The complex modulus ($|G^*|$) and phase angle (δ) for all asphalt binder were measured over the range of temperature under unaged and short termed aged conditions. Various rutting parameters (at binder level) were estimated using these measurements. As expected, $|G^*|/\sin\delta$ values decreased with increase in temperature for all binders under aged and unaged condition. However, the rate of decrease in $|G^*|/\sin\delta$ with temperature for modified binders was less as compared to unmodified binder under both aging conditions. This indicates that polymer modification reduced the temperature susceptibility of the binder. The complex viscosity data were fitted with Cross Williamson's model to determine low-frequency viscosity. Multiple stress and creep recovery test was also performed.

The rutting parameter $|E^*|/\sin\delta$ for different AC mixtures were estimated at various temperature and frequencies. As expected, $|E^*|/\sin\delta$ values decreased with increase in temperature for all mixtures. The mixture containing modified binder showed higher values of as compared to the mixture prepared with unmodified binder. This indicates that the modification of the asphalt

binder improves the rut resistance of AC mixtures. The mixtures with 19.0 mm nominal maximum particle size (NMPS) showed the higher value of $|E^*|/\sin\delta$ as compared to mixtures prepared with 13.2 mm NMPS aggregates. This indicates that aggregate gradation with higher NMPS exhibits better performance under rutting. Wheel rut tests were also conducted on these mixtures (using different specimen geometries) using Flat Wheel Loaded Test (FWLT). Flow number test and modified flow number test was also conducted.

The correlation among various binder and mixture rutting parameters were evaluated. MSCR test parameters showed better correlation with mixture rutting resistance. The rut resistance trends obtained from FWLT and flow number tests were similar to $|E^*|/\sin\delta$ values obtained with different mixtures. The modified flow number test showed better correlation as compared to traditional flow number test. The Dynamic Stability (DS) and rut depth at 10000 passes showed very good correlation. Hence DS can be used as the rut susceptibility indicator for asphalt mixture. This in turn can reduce the testing time involved with wheel rut test.

Three different specimen geometries were used in FWLT to determine the rutting propensity of different mixtures. The DS observed using 4-inch specimens was higher when compared to 6 inch and slab specimens. Also, the DS obtained using the slab was higher than the 6-inch specimen. In order to examine the effect of the specimen geometry on the rut measurement, Pearson correlation analysis was carried out. The highest correlation was found between slab & 4-inch specimen, followed by 6-inch & 4-inch geometry. Further, least correlation was found between 6-inch & slab specimen. Specimen geometry at 4000 passes, the correlation between 4 inch & slab specimens were found significant. The rut depth observed with slab specimen was higher as compared to the rut depth observed in case of 4-inch specimen. Also, the measured rut depth was higher in case of 6-inch specimen as compared to the 4-inch specimen.

Even under extremely controlled laboratory conditions, the plot of rut

depth against the number of passes shows significant scatter. This scatter can be attributed to variation in constituent materials, specimen fabrication, aggregate skeleton, and testing practices. A novel probabilistic approach to characterize the scatter found in rutting test results has been proposed in this study. For this purpose, several slabs of asphalt concrete mixtures were tested for rutting susceptibility using wheel tracking device. Initially, wheel rut test data from each slab was fitted with Francken model and power law model to smoothen the data. The smoothened data was further used to predict (i) rut depth, or (ii) number of passes at prespecified locations. The data thus generated (at a specific rut depth or number of passes) was fitted with normal, lognormal and Weibull distribution. Statistical analysis indicated that these distributions could be used to describe wheel rut test results well. Using predicted values (rut depth or the number of passes) made for a particular probability, Probabilistic Rutting Curve (PRC) were constructed. Based on the location of PRCs, it can be concluded that PRCs obtained assuming Weibull distribution results in conservative rut estimate, while those based on lognormal distribution results in overestimation. PRCs obtained assuming normal distribution were intermediate to those obtained assuming Weibull and the lognormal distribution. Further, significant differences were found between conventional approach and PRCs constructed in this research. The proposed methodology combines advantages of traditional testing protocol and probabilistic approaches. These PRCs can be conveniently used in conjunction with reliability-based pavement design and quality control protocols.

Keywords: Permanent Deformation, Rutting, Asphalt, Asphalt concrete, Probabilistic Approach, Specimen Geometry, Aggregate Degradation, etc.

सामान्य सारांश

इस अध्ययन का मुख्य उद्देश्य मॉर्शल संघनन के दौरान गिट्टी के ग्रेडेशन में होने वाले परिवर्तन एवं डामर कंक्रीट के रटिंग व्यवहार को प्रयोगशाला की जांच, अनुभविक सांख्यिकीय विश्लेषण और संभाव्यता मॉडलिंग के द्वारा समझना था । इस अध्ययन के उप–उद्देश्य और तदनुरूपी परिणाम निम्नानुसार हैं ।

1. संघनन प्रक्रिया के दौरान डामर कंक्रीट में होने वाले प्रभावों का मूल्यांकन करना । संघनन प्रक्रिया के दौरान गिट्टी के ग्रेडेशन में होने वाले परिवर्तन पर नमूने के आकर, डामर का प्रकार एवं गिट्टी के ग्रेडेशन का अध्ययन प्रायोगिक जांच के माध्यम से किया गया । इस प्रकार उत्पंन डेटा का इस्तेमाल सांख्यिकीय विश्लेषण के माध्यम से कई अनुभविक निष्कर्ष पर पहुंचने के लिए किया गया था ।
2. डामर के मौलिक गुणों का परीक्षण और उन्हें डामर मिश्रण के रटिंग व्यवहार से सम्बन्धित करना । रटिंग पर डामर के प्रकार एवं गिट्टी के ग्रेडेशन के प्रभाव का परीक्षण योगशाला प्रयोगों का उपयोग करके मूल्यांकित किया गया था । इसके साथ ही डामर के इंजीनियरिंग और विस्कॉइलास्टिक गुणों का परीक्षण किया गया । कई अनुभवजन्य और यंत्रवत आधारित दृष्टिकोण का उपयोग कर बाइंडर गुण और मिश्रण गुणों के बीच सहसंबंध पाया गया ।
3. रटिंग के प्रयोगशाला परीक्षण के तहत प्राप्त डेटा उपयोग कर एक संभाव्य दृष्टिकोण के विकास किया गया । घटक सामग्री गुणों में भिन्नता, विभिन्न परीक्षण अभ्यास आदि के कारण रटिंग परिणामों में बिखराव पाया गया । यह अन्य शोधकर्ताओं की खोज के साथ सहमति में हैं । इस शोध के संभाव्य दृष्टिकोण में रटिंग संभाव्य–वक्र का निर्माण प्रस्तावित किया गया है । इस प्रकार से निर्मित रटिंग संभाव्य–वक्र का इस्तेमाल आसानी से विश्वसनीयता आधारित सड़क ढांचे के डिजाइन में इस्तेमाल किया जा सकता है ।

संकेतशब्द : स्थायी विरूपण, रटिंग , डामर, डामर कंक्रीट, संभाव्य दृष्टिकोण, नमूना ज्यामिति, आदि।

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List of Abbreviations

AC	Asphalt Concrete
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AIC	Akaike Information Criterion
AICc	Akaike Information Criterion corrected
AMPT	Asphalt Mixture Performance Analyser
ANOVA	Analysis of Variance
BC	Bituminous Concrete
BIC	Bayesian Information Criterion
CCAR	Change in Coarse Aggregate Ratio
CFCA	Change in Fine Aggregate Coarse Ratio
CI	Change Index
CoV	Coefficient of Variance
CRMB	Crumb Rubber Modified Bitumen
DS	Dynamic Stability
DSR	Dynamic Shear Rheometer
FAC	Fine Aggregate Coarse Ratio
FLWT	Flat Loaded Wheel Tester
FN	Flow Number
GoF	Goodness of Fit

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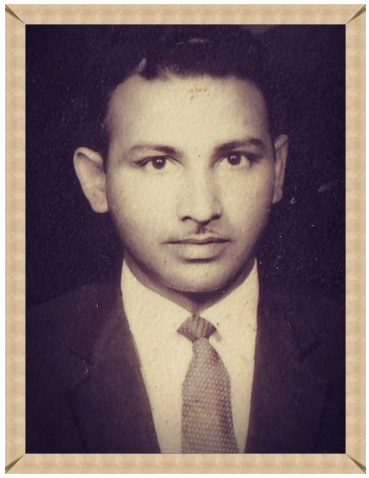
HMA	Hot Mix Asphalt
IDT	Indirect Tensile Strength
IRC	Indian Road Congress
LFV	Low Frequency Viscosity
MLE	Maximum Likelihood Estimates
MSCR	Multiple Stress Creep Recovery
NCHRP	National Cooperative Highway Research Program
NFN	Modified Flow Number
NLogL	Negative Log Likelihood
NMPS	Nominal Maximum Particle Size
OBC	Optimum Binder Content
PCIPS	Percentage Change in Individual Particle Size
PCS	Primary Control Sieve
PCV	Percentage Change in VMA
PDF	Probability Density Function
PID	Proportional Integral and Derivative
PMB	Polymer Modified Bitumen
PRC	Probabilistic Rutting Curve
PRC	Probabilistic Rutting Curve
RD	Rut Depth

RMSE	Root Mean Square Error
RTFO	Rolling Thin Film Oven
SCS	Secondary Control Sieve
SMA	Stone Mastic Asphalt
TTSP	Time-Temperature Superposition Principle
VFA	Voids Filled with Asphalt
VG	Viscosity Grade
VMA	Voids in Mineral Aggregates
WTS	Wheel Tracking Slope
ZSV	Zero Shear Viscosity

Dedicated to My Grandfather.



Late Shri Brindawan Singh

Jan 02^{nd} 1934 – *Dec* 17^{th} 1998

यद्यदाचरति श्रेष्ठस्तत्तदेवेतरो जनः।
स यत्प्रमाणं कुरुते लोकस्तदनुवर्तते॥

(तृतीय अध्याय, श्लोक 21)