Electromagnetic Gauges for Defining In-Place HMA Density

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Abstract

Ensuring that an HMA mat is compacted uniformly to an adequate density is very important to the performance of the pavement structure over the project life.Density is a factor used in many pavement design methods, including AASHTO. Current methods of determining in-place density of hot mix asphalt (HMA) with cores are destructive. Because of this many agencies make use of nuclear density gauges for rapid, non-destructive density readings in the field. Lenz (2011) cites numerous studies indicating that “compaction is the greatest determining factor in dense graded pavement performance.”When Maxwell's equations are expressed in (A, Ò) form, two equations result in which A and Ò are coupled and the variables are not separated. Electro dynamicists then arbitrarily alter these equations by making two simultaneous asymmetrical regaugings, designed so that the net regauging is symmetrical, i.e., the net force fields are unchanged.

Keywords: HMA, electromagnetic, electromagnetic gauges, regauging

Introduction

Density is an important component of hot-mix asphalt (HMA) pavement quality and long-term performance. Insufficient density of an in-place HMA pavement is the most frequently cited construction-related performance problem. Density is measured as part of the quality control process by the paving contractors and for the quality assurance process by the Iowa Department of Transportation (Iowa DOT). Contractors falling short of required density on placed HMA are paid less than the full contract amount, and payment factor discounts can range from 98 percent of the contract price to as low as 65 percent.Traditionally, two techniques have been used to estimate in-place HMA density: laboratory tests on pavement cores (Figure 1.1a) and in-situ nuclear gauge measurements (Figure 1.1 b). The firsttechnique uses a destructive procedure, in which cores are extracted from a pavement to directly measure the thicknesses and the volumetric properties of pavement layers. Although this method provides accurate density measurements, it is time consuming and provides limited information because cores are typically taken every 1000ft. On the other hand, the nuclear gauge is a nondestructive technique that can be used to provide reasonably accurate estimates of the HMA layer density. However, this technique also has some drawbacks. First, it provides limited information about the layer density, since nuclear measurements are usually taken with high spatial spacing. Second, nuclear gauge operation requires special licensing because it uses radioactive material. Hence, it can be used only by authorized personnel.

Recently, electromagnetic (EM) density gauges (Figure 1.1 c) have entered the market as an alternative to the nuclear density gauges and the coring process. These nonnuclear devices use EM signals to measure in-place density. The EM density gauges have the advantages of completely eliminating the licenses, training, specialized storage, and risks associated with devices that use a radioactive source (Romero, 2002). However, similar to the traditional methods, the nonnuclear density gauges are not able to provide continuous information of the entire pavement either.



Figure 1.1 a Coring Figure 1.1b Nuclear gauge Figure 1.1c EM gauge

Influence Electromagnetic Gauge Measurements

Earlier models of the Pavement Quality Indicator (namely the Pavement Quality Indicator 100 and the Pavement Quality Indicator Model 300) and the PaveTracker are affected by the surface mix temperature [1]. Gauge reading decreased with a decrease in surface mix temperature [2]. Liao et al., found that, on an average, the gauge reading decreased by 16kg/m3 with a temperature drop of 500C [2]. Likewise, they was also found that the gauge reading (measured using a PaveTracker) increased with the increase in surface temperature; and this is more profound for coarse mixes (19mm) than for fine mixes (9.5mm) [3]. However, it was found that the latest electromagnetic gauges (Pavement Quality Indicator Model 301 and PaveTracker Model 2701-B) are hardlyaffected by pavement or mat surface temperature [4]. Williams and Hall verified this by measuring the density using these two electromagnetic gauges at two temperatures (high temperature of 1800F i.e., just behind the finish roller; and low temperature was after mat had cooled considerably i.e., approximately 1000F). They found through their analysis (t-tests) that the electromagnetic devices' measurements were unaffected by temperature (i.e., t-tests' results indicated no significant difference, p-value>0.05). Thus,it can be assumed that manufacturers have corrected these gauges to account for temperature variability while providing density readings.

Influence of type of mix and aggregate size on electromagnetic gauge readings

Electromagnetic gauges are affected by the type of mix (i.e., coarse or fine) [1]. Sargand et al. found that the PaveTracker displayed more accurate results for measurements that were made on fine mixes than on coarse mixes [5]. Larsen and Henault observed that in spite of changing the algorithm of the Pavement Quality Indicator and the PaveTracker (to provide improved results), the measured density values were affected by the mix design (i.e., aggregate size and proportion, and particle segregation) [7]. Even Schmitt et al. found that electromagnetic gauges are affected by mixture- and project-specific factors like: aggregate source, design loads, laboratory air voids, asphalt content, aggregate specific gravity, and pavement layer thickness [8]. The newer gauge models like the PaveTracker Model 2701 were also affected by various factors like: contractor, traffic level, aggregate type, NMAS, roller passes, and moisture condition (i.e., wet and dry conditions). Pavement Quality Indicator Model 301 was affected in the single mode by factors like: station, roller passes, temperature, and distance across pavement width. In multi-mode (method of data collection) it was affected by factors like: site, station, pavement width, contractor, aggregate type, binder content, roller pass, and distance across pavement width. Williams and Hall indicated that the gauges were significantly affected by large aggregate size and void size (37.5mm mix). They measured density at the same spot (for all locations) using both the gauges (the PaveTracker PlusTM Model 2701-B and the Pavement Quality Indicator Model 301). It was found that the gauge type did not show significant differences in the 12.5mm mix, which has smaller voids. However, it showed significant differences in the 37.5mm mix, which has larger voids (this was indicated in the ANOVA table withpvalue<0.0001) (24). Liao et al. found that gauge measurements on fine mixes (9.5mm) have better correlation with cores than differences of coarse mixes (19mm).

Methods to calibrate electromagnetic gauges to get more accurate density results

The electromagnetic gauge can be made to produce more accurate readings by correcting it for errors. Schmitt et al. recommended that electromagnetic gauges must be calibrated daily at each project site (to offset the effect of various factors) [9]. They also found that nuclear gauge readings were the most appropriate means to calibrate an electromagnetic gauge [9]. They also recommended that technicians using electromagnetic gauges take at least 30 readings within each lot to ensure acceptable confidence levels [9]. Rao suggested that an optimal adjustment function must be calculated by correcting the raw electromagnetic readings to match core readings. This should include an additive shift and a slope factor [10].

They suggested that the gauge readings can be corrected (using the *slope* factor) by multiplying a constant correction factor (or slope term) to the raw gauge readings (20). Also, the gauge readings can be corrected using the slope and intercept method, wherein, the electromagnetic readings are adjusted by multiplying a slope term (C3) and adding an intercept term (C4) [10]. They recommended that a calibration factor must be determined using the slope function and based on 10 calibration points; and this must be implemented for agency use. Daily calibration for each mix design is recommended when the project involves multiple days of paving. The use of 10 test points and a correlation using the *slope* method is optimal to develop accurate calibration factors. Finally, the study recommends that independent calibrations be established for each day of paving [10]. Also, Smith and Die-fender suggest that for each project, if the gauge is calibrated on a test strip before actual fieldtesting and measurement is performed, then it can be used for quality control (Quality Control) and quality assurance (Quality Assurance) [11].

Comparison of electromagnetic gauges and recommendations for QC/QA purpose

Earlier studies by Romero indicate that the Pavement Quality Indicator Model 300, the Pavement Quality Indicator Model 300+ (i.e., modified algorithm which gives improved results), and the PaveTracker cannot be used for Quality Assurance purpose, but they can be used for Quality Control purpose [12]. Allen et al. and Andrewski also found that the Pavement Quality Indicator Model 300 can be used for quality control [13]. Hurley, G.C. et al. found that the Pavement Quality Indicator Model 301 gives more accurate results than the Pavement Quality Indicator Model 300 and the PaveTracker[14].Smith and Diefender found that the Pavement Quality Indicator Model 301 can be used for Quality Control and Quality Assurance; provided it is calibrated daily on a test strip for each project before actual testing and measurement is performed.

Romero recommended that the electromagnetic gauges (Pavement Quality Indicator Model 300 andPaveTracker) should be operated by experienced professionals, and that a reference standard should be developed for the Pavement Quality Indicator just like the PaveTracker[14]. Kvasnak et al. suggested that to ensure the appropriate implementation of electromagnetic gauges, there is a need for additional work that considers the following elements: 1. Utilization of test strips 2. Increase the electromagnetic gauge testing frequency 3. Evaluate new electromagnetic gauges that have entered the construction industry.

Conclusion

Electromagnetic gauges can possibly replace nuclear gauges to measure inplacedensity of pavements for quality control purposes. This conclusion is based on the evidence from the results from the data analyses (paired and pooled t-tests).Electromagnetic gauge densities might not even require adjustment to core densities (i.e., unlike nuclear gauges) because the results from these two methods of measurement were not significantly different at 95% confidence level.The electromagnetic gauges should be used in the un-sanded condition rather than in the sanded condition.The densities obtained from electromagnetic gauges and adjusted using the CoreLok densities should be used because these adjustment factors provided the best results in comparison to adjustment factors utilizing nuclear gauges or AASHTO T 166 (SSD methods). In other words, the former adjustment factors were not significantly different in more lift comparisons than the latter adjustment factors.

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