EFFECT OF SCARIFICATION ON ASPHALT PATCH JOINT BOND STRENGTH

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Transportation Research Board
84th Annual Meeting
January 9-13, 2005
Washington, D.C.

EQUIVALENT WORD COUNT: 7,499

ABSTRACT
Constructing patches in asphalt pavements typically involves sawing vertical cuts into the roadway surface and laboriously breaking up and removing the deteriorated material before repaving. An appealing, alternative removal technique utilizes a portable asphalt recycling machine that simultaneously cuts and pulverizes the asphalt concrete. While the saw-cut method produces a smooth vertical face on the existing asphalt pavement, the portable recycling machine imparts a rough scarification to the pavement edge. The purpose of this research was to investigate the effects of scarification on patch joint bond strength. An experimental pavement section was constructed in Pleasant Grove, Utah, to specifically compare the bond strengths of saw-cut and scarified patch joints. Twenty-five cores were extracted from each patch joint both before and after winter to additionally evaluate the effects of in-situ freeze-thaw cycling on the bond strength of each joint. The density and shear strength of each core were measured, and statistical techniques were employed to separate the effects of scarification and density on bond strength. Analysis-of-covariance (ANOCOVA) testing was used to compute adjusted mean bond strengths at the average density for the saw-cut and scarified specimens. The adjusted average strengths of the scarified cores were 20.8 percent and 25.1 percent higher than the corresponding strengths of the saw-cut cores before and after winter, respectively. Furthermore, the statistical analyses showed that the introduction of a scarified face improved patch joint bond strength for all compaction densities and that the importance of achieving proper compaction during construction increases as the joint ages.

Key Words: Asphalt Patching, Bond Strength, Joint Compaction, Load Transfer Efficiency, Scarification

INTRODUCTION

Partial pavement removal and replacement is a common technique for maintaining and rehabilitating damaged asphalt roadways. When deteriorated pavement is replaced with new material, a joint is created between the existing pavement and the newly placed patch. The joint potentially constitutes a failure plane that can accelerate the development of pavement distresses in the vicinity. Indeed, the quality of the interface between the existing pavement and the patch material has a significant impact on the performance of the affected road and the overall life-cycle costs associated with maintaining the pavement in a functional condition. The impact of joint quality on pavement maintenance costs is especially exacerbated in cities and towns, where cuts are routinely made to service or install water lines, electrical lines, sewer piping, communication cables, and other utilities.

Traditionally, asphalt concrete that must be removed because of deterioration or utility work is saw-cut and excavated with a backhoe. The process of breaking the asphalt into manageable pieces for hauling away can be time-consuming and laborious. Furthermore, the smoothly sawn vertical faces of the original pavement then offer minimal mechanical interlock with the patch material. An appealing, alternative removal technique utilizes a portable asphalt recycling machine comprised of a large rotating drum fitted with metal cutting teeth and powered by an onboard diesel engine. The machine is readily transported by trailer behind a standard pickup truck; can be unloaded and placed in operation within just a few minutes after its arrival on site; and easily and securely mounts to the bucket of a loader, backhoe, or skid-steer, depending on the model, using hydraulic actuators. It simultaneously cuts and pulverizes asphalt concrete and imparts a rough surface to the vertical cut faces of the original pavement due to the scarifying action of the rotating drum. The pulverized material may then be utilized on site as backfill material where appropriate or as base material for pavement reconstruction, or it may be readily loaded into a truck and transported off site for other uses.

The scarification resulting from the asphalt recycling machine has the potential to improve patch performance compared to the saw-cut method of asphalt removal by increasing the bond strength of patch joints. Increased aggregate interlock between patch materials and original pavement can reduce cracking in the vicinity of the joint, minimize joint faulting, and decrease water ingress through the joint. Increases in patch longevity can in turn lead to reductions in overall pavement maintenance costs. However, the extent to which patch durability is actually enhanced by the rough surface texture introduced by the rotating drum has not been previously investigated. While research has been performed on interface properties between asphalt lifts and the performance characteristics of different longitudinal joint construction techniques, those studies were limited in scope to tack coat type and curing time, asphalt cement type and aggregate gradation, and joint geometry (*1, 2, 3*). Information on the strength characteristics of asphalt joints with different surface textures is largely absent from the literature. Therefore, the purpose of this research was to specifically investigate the relative effects of saw-cutting and scarification on patch joint bond strength. This paper discusses failure modes and testing methods relevant to joints in asphalt pavements, provides a summary of the experimental methodology utilized in the research, presents the results obtained from the study, explains the statistical analyses utilized to evaluate the data, and offers conclusions about the effects of scarification on patch joint bond strength.

PATCH JOINT BONDING CHARACTERISTICS

Asphalt pavement joints deteriorate due to the combined forces of shear and tension. Shear is induced along a given patch joint as the pavement sections on opposite sides of the joint are loaded unequally. For example, the development of shear occurs in transverse joints as traffic approaches and retreats from the joint, while shear is created in longitudinal joints as wheel loads traverse the pavement immediately adjacent to the joint. Tensile forces are introduced as the asphalt expands and contracts due to temperature fluctuations and as traffic loads flex the pavement, causing tension in the top or bottom of the pavement layer depending on the direction of bending. These tensile forces can decrease the shear strength of the patch bond by pulling the joint apart and thus decreasing the friction between the two vertical surfaces comprising the joint.

The shear strength of a joint is dependent upon the amount of adhesion and aggregate interlock present between the bonding faces (*4, 5*). While adhesion is a property of the asphalt and tack coat materials, aggregate interlock is influenced to a large degree by compaction density (*5, 6, 7*). Low densities at joints can result in cracking and decreased shear strength in the vicinity of the joint because of bonding loss between the aggregate particles, asphalt cement matrix, and adjacent patch material (*1, 6, 8*). As the cracks widen, the pavement also becomes more susceptible to water ingress, which can lead to stripping of the asphalt, erosion of the base, decreased bearing capacity, faulting, and further cracking of the asphalt layer (*6*). Therefore, as the shear strength of the boundary decreases, the probability of poor joint performance increases.

Varying methods exist for measuring the strength of bonding between two asphalt surfaces. In the laboratory, destructive methods include the pull-off test, the wedge-splitting test, and the direct-shear test (*2, 3*). The pull-off and wedge-splitting tests directly measure the tensile strength of a specimen by pulling the specimen apart in the direction normal to its seam, such as would occur in an asphalt joint subject to thermal contraction, or by driving a standard wedge into a starter notch cut along the seam in one face of the specimen (*3*). The direct-shear test applies a shear load across the joint or seam in a specimen and thereby measures its overall shear strength in a configuration similar to the actual loading experienced by a pavement joint under traffic.

For field testing, the falling-weight deflectometer (FWD) can be utilized to measure the quality of a joint interface in terms of a load transfer efficiency (LTE). The LTE is a measure of the ability of a crack or joint to transfer loads between the pavement sections on either side of it. A high-strength joint will have an LTE close to 100 percent, indicating that all of the load is transferred, whereas a completely disconnected surface will have an LTE of 0 percent, indicating no horizontal transfer of the shear force.

In order to obtain the LTE, the FWD loading plate is placed adjacent to one side of the asphalt joint, and deflections measured in response to the load are recorded on both sides of the joint. The LTE is typically calculated by dividing the deflection 12 in. away from the middle of the loading plate on the opposite side of the joint by the deflection measured under the loading plate (*9*). To account for the deflection that would occur in the absence of a joint or crack, this value is often divided by a normalizing factor computed as the ratio between deflections measured at the same radial distances from the loading plate on an intact section of the same pavement. The correction value is based on the assumption that both sides of the joint under examination are composed of the same material with similar stiffness properties. In addition to determining the LTE, recorded FWD deflections at several radial distances away from the loading plate can be used in computer software to backcalculate the modulus values of individual pavement layers if the thicknesses of each pavement layer are known.

EXPERIMENTAL METHODOLOGY

In order to test the difference in shear strength between saw-cut and scarified edges, an asphalt testing yard in Pleasant Grove, Utah, was secured for the research. The portable asphalt recycling machine shown in Figure 1 was used to make a 48-in-wide experimental cut approximately 75 ft in length through a 6-in. layer of asphalt concrete. Figure 2 shows the textured vertical face resulting from the scarification process. A saw cut was then made parallel to the scarified section approximately 8 ft to one side, and all of the asphalt between the saw cut and the outer scarified edge was removed as shown in Figure 3. This configuration ensured that the adjacent asphalt concrete and the underlying base materials at both joint locations were as similar as possible. A tack coat was sprayed onto both vertical cut faces, and a hot-mix asphalt patch was placed and compacted in the trench in October 2003 by a local paving contractor as shown in Figure 4. The patch material was reportedly an AC-20 with a maximum aggregate size of 0.5 in. The asphalt cement content was 5.5 percent by weight of total mix.

To facilitate sampling before and after winter, the patch was subdivided into two sections each about 35 ft in length. Researchers removed 25 cores from each side of one of the patch sections approximately one month after patch placement and then extracted the same number of cores from the second patch section in late April 2004. The second set of cores was analyzed to evaluate the effects of in-situ freeze-thaw cycling on the overall bond strength of each joint. As depicted in Figure 5, a portable 6-in. core drill was utilized for the extractions, in which each core was centered as closely as possible on the respective joint. After removal, the cores were prepared for testing at the Brigham Young University (BYU) Highway Materials Laboratory. Each specimen was trimmed using a masonry saw to create flat, parallel end faces and then air-dried to constant weight. The heights, weights, and diameters of the cores were then measured in order to calculate the bond area and density of each specimen. Photographs of typical cores from the saw-cut and scarified joints are given in Figure 6.

A direct shear test was then utilized to measure the quality of the joint interface for both types of patch joints. As mentioned earlier, this testing method measures aggregate interlock more directly and simulates roadway loading conditions under trafficking more appropriately than alternative testing configurations. A specially manufactured testing apparatus was used in a servo-controlled hydraulic testing machine to shear each core at a constant strain rate of 0.05 in./min as shown in Figure 7. The load was applied across the joint in the direction parallel to the longitudinal axis of the core. The joint was carefully aligned within a 1-in. shear zone provided in the testing apparatus to accommodate variability in joint locations from one core to the next. Each core was loaded to failure at room temperature, after which the bond strength was calculated for each specimen by dividing the maximum sustained load by the bond area over which the load was applied.

In addition, FWD testing was utilized to calculate the LTE for each patch joint after winter and to facilitate backcalculation of the asphalt and base layer modulus values. The FWD used in this study had sensors stationed at 0 in., 8 in., 12 in., 24 in., 36 in., 48 in., 60 in., and -12 in. from the loading plate. The patch side of each joint was loaded as illustrated in Figure 8, and the LTE was calculated from the deflections recorded at 0 in. and -12 in. The FWD operator conducted tests at approximately 8,000 lbf and 10,000 lbf at five points along each patch joint, and the recorded deflections were used to compute an equivalent deflection for a 9,000-lbf load.

In addition to measuring deflections across the patch joints, intact sections of the patch and the original pavement were evaluated using FWD for the purpose of computing the ratio between deflections measured at the 0-in. and -12-in. sensors in the absence of a joint.

Research was also performed at the testing site to evaluate the stiffness and water content of the aggregate base material immediately beneath the joints. After all of the cores had been removed, two test holes were drilled through the asphalt along each joint with a hammer drill equipped with a 1.25-in.-diameter bit. In each of these four holes, a dynamic cone penetrometer (DCP) test was performed using a 17.6-lb drop weight to assess the stiffness of the base material with depth. To evaluate the moisture state of the base layer under each joint, dielectric values of the base layer were recorded at 1-in. depth increments using a 50-MHz downhole probe about 3 ft in length. The dielectric value of an aggregate base material increases with increasing liquid water content (*10*).

TEST RESULTS

The test results include measured shear strengths and calculated densities for each core specimen collected before and after winter, as well as LTEs computed from FWD data after winter. Stiffness and dielectric profiles are also given.

Table 1 provides a summary of the bond strength and density data. Of the original 50 cores sampled before winter, 20 scarified cores and 21 saw-cut cores were analyzed; after winter, 21 saw-cut cores and 22 scarified cores were analyzed. The others were either damaged during laboratory preparation or not correctly centered on the joint during testing. Statistical techniques were used to analyze both the bond strength and density data. Numerous cores were taken to improve the accuracy of the average sample responses by reducing their variation from the “true” values, or population means. The population mean for a particular response, such as bond strength, for example, would be determined by coring 100 percent of a given joint and computing the average bond strength from all of the specimens. While cost and other constraints typically prohibit such extensive analyses, information about populations can be inferred from sample data. The more samples, the more reliable is the average sample response.

Table 1 suggests that the average sample strength of the scarified cores was 19.7 percent higher than that of the saw-cut cores before winter and 3.4 percent higher than that of the saw-cut specimens after winter. However, as stated earlier, asphalt compaction density can impact joint strengths. As evidence of this assertion, Figure 9 shows a plot of density versus bond strength for each set of cores before and after winter. This plot shows that density has a marked impact on the overall bond strengths of the tested specimens. If densities are not uniform along both sides of the length of the patch, then the density variable must be accounted for in any meaningful statistical evaluation of the influence of scarification on bond strength. That is, simply averaging the measured strengths of the specimens does not accurately reflect the true relationship between bond strength and joint type.

Therefore, in order to investigate the statistical significance of the observed variability in density and ultimately the difference in bond strength between the joints, two-sample *t*-tests were performed. The *t*-test allows comparison of two population means while controlling the probability of making a Type I error. A Type I error is committed upon rejection of a true null hypothesis in favor of a false alternative, where the null hypothesis is the postulation that the population means are equal and the alternative is the conjecture that one mean is larger than the other. The probability of occurrence for a Type I error is denoted by the symbol α, which is selected by the researcher as the tolerable level of error for the given experiment. The value of

α is compared to the level of significance, or *p*-value, computed from the sample data in the *t*-test, where the *p*-value represents the probability of observing a sample outcome more contradictory to the null hypothesis than the observed sample result. When the *p*-value is less than or equal to α, the null hypothesis can be rejected, leading to acceptance of the alternative hypothesis. However, when the *p*-value is greater than α, one must conclude that insufficient evidence exists to reject the null hypothesis.

In the analysis of density, the saw-cut and scarified cores were each considered samples of separate populations, and *t*-tests were performed to evaluate the variability in densities before and after winter for each joint separately. The null hypothesis in each test was that the average population density before winter was equal to the population density after winter for a given joint type, and the alternative hypothesis was that they were not equal. Analyses were conducted using a standard error rate of 0.05. At this α level, only a 5 percent chance exists for falsely claiming that the joint densities were significantly different. After the data were checked to ensure compliance with statistical test requirements, *t*-tests were performed using a pooled standard deviation and yielded *p*-values less than 0.0001 for both joints. Because the *p*-value in each case is less than the selected value of α, one may conclude that the densities before and after winter for each joint type are significantly different; that is, the compaction quality varied along the length of the patch, with higher densities achieved in the section sampled after winter than in the section sampled before winter.

The core densities of the saw-cut and scarified joints were also compared to each other before and after winter. In these tests, the null hypothesis was that the joint densities were equal at the given sampling time, and the alternative hypothesis was that they were not equal. The *p*-values resulting from these analyses were 0.856 and 0.048 for data collected before and after winter, respectively. Thus, one may conclude that the saw-cut joint had a higher average density than the scarified joint in the section sampled after winter. These differences in density may explain the apparent increase in strength of the saw-cut joint during winter and the simultaneous decrease in strength of the scarified joint reported in Table 1.

Overall, these analyses indicate that a significant difference in density exists between the saw-cut and scarified joints before and after winter. Uncontrolled variation in density potentially masks the influence of scarification on the bond strengths of the joints; in such a case, the density and scarification variables are said to be confounded. In order to separate the effects of density and scarification on bond strength, a statistical analysis of covariance (ANOCOVA) was performed. An ANOCOVA normalizes the response variable, in this case shear strength, to account for variations in starting conditions, such as density. By applying this normalizing factor, variations in bond strength as a result of the different surface textures on the joint interfaces could be more precisely evaluated.

ANOCOVA tests were thus performed to measure the differences in shear strength in the saw-cut and scarified joints both before and after winter. The significant predictor terms in the model included joint type and density. The null hypothesis in these analyses was that the average population bond strengths of the saw-cut and scarified joints were equal, and the alternative hypothesis was that the scarified joint had a higher average population bond strength than that of the saw-cut joint when adjusted for density variations. For the data collected before winter, the adjusted mean bond strengths at the average density for the saw-cut and scarified specimens were 11.93 psi and 14.41 psi, respectively. Thus, the average bond strength for the scarified cores was 20.8 percent larger than the average for the saw-cut specimens after both were adjusted for differences in densities between cores. The *p*-value for this difference in means was 0.026, indicating that the shear strength of the scarified edge was significantly higher when compared on the basis of equivalent density.

A similar statistical analysis was performed on the data collected after winter. In this case, the adjusted mean bond strengths of the saw-cut and scarified joints were 11.03 psi and 13.80 psi, respectively. The adjusted mean bond strength of the scarified cores was thus 25.1 percent larger than the saw-cut samples after differences in density were considered. The results of the hypothesis test yielded a *p*-value of 0.016, which affirms that scarification results in greater joint strength than saw-cutting. These data, which necessarily account for spatial density variations along the joints, indicate that the relative strength of the scarified joint compared to the saw-cut joint actually increased from 20.8 percent to 25.1 percent after both joints were subjected to freeze-thaw cycling during the winter. The statistical analysis also showed that the interaction between joint type and density was insignificant. That is, the difference in shear strength between joint types was consistent for all compaction densities.

Another ANOCOVA model was created to evaluate the influence of freeze-thaw cycling on the overall shear strength of both patch joints. The significant predictor terms in the model included joint type, density, time of sampling, and the interaction between density and time. Again, the interaction between density and joint type was not significant in this model. The null hypothesis was that the average shear strength after winter was the same as the shear strength before winter, and the alternative hypothesis was that the shear strength after winter was less than the shear strength before winter. This hypothesis test produced a *p*-value of 0.0042, indicating that a significant loss of strength over the course of one winter occurred for both joint types.

A second hypothesis test was also performed using this same ANOCOVA model to evaluate the influence of density on bond strength over time. The null hypothesis in this test was that the interactions between density and time were the same before and after winter, and the alternative hypothesis was that the interactions between density and time were not equal before and after winter. The results of the statistical analysis indicate that the influence of density is significant over time, with a *p*-value of 0.0097. This indicates that the importance of proper compaction during construction increases as the joint ages.

Backcalculations of modulus values from FWD data showed that the patch and existing pavements have stiffness values of 1200 ksi and 550 ksi, respectively. Thus, a correction factor could not be utilized in computing the LTE because the patch and existing pavement had significantly different modulus values. Therefore, the direct ratio of deflections is reported as the LTE in this paper. Testing on the saw-cut joint yielded an average LTE of 82.1 percent and a standard deviation of 3.1 percent, while the scarified joint had an average LTE of 81.2 percent and a standard deviation of 2.0 percent. A paired *t*-test on these data yielded a *p*-value of 0.611, indicating that differences between the bond strengths of the two joints are not discernable from the LTE data.

Figure 10 shows the stiffness and dielectric profiles for the four test holes. The profiles indicate that the base material is similar for each joint location. Backcalculations of the base layer modulus using FWD data show similar structural characteristics of the layer as well, with values ranging between 13 ksi and 15 ksi. Therefore, base layer support was assumed to be uniform in the vicinity of the patch site and not considered as a variable.

CONCLUSION

This study investigated the influence of scarification on the shear strength of asphalt pavement patch joints. An experimental pavement section was constructed to specifically compare the bond strengths of saw-cut and scarified patch joints. Cores were extracted before and after winter along the patch joints and sheared at a constant strain rate in a specially manufactured test apparatus. The bond strength for each core was calculated as the maximum sustained load divided by the bond area. The density was computed from the mass and physical dimensions of each specimen.

Significant differences in the densities of specimens collected from both joint types before and after winter were identified, which suggests that the compaction quality varied along both sides of the length of the patch. Moreover, the data showed that density had a marked impact on the overall bond strengths of the tested specimens, where higher densities were generally associated with higher bond strengths and lower densities with lower bond strengths. Therefore, statistical techniques, including *t*-testing and ANOCOVA testing, were employed to separate the effects of scarification and density on bond strength.

In the ANOCOVA, adjusted mean bond strengths were computed at the average density for the saw-cut and scarified specimens. For the data collected before winter, the average bond strength for the scarified cores was 20.8 percent larger than the average bond strength of the saw-cut specimens after both were adjusted for differences in densities between cores. For the data collected after winter, the mean bond strength of the scarified cores was 25.1 percent larger than the saw-cut samples after differences in density were considered. These analyses indicate that the relative strength of the scarified joint compared to the saw-cut joint actually increased after both joints were subjected to freeze-thaw cycling during the winter. Statistical analyses not only confirmed that these differences in shear strength were significant but also showed that the interaction between joint type and density was insignificant; this indicates that the introduction of a scarified face improved patch joint strength for all compaction densities.

A statistical model was also created using the combined effects of density and time of sampling for both joint types. This model was used to compare the effects of time and density on shear strength. As expected, both joints experienced a significant decrease in shear strength over the winter months due to repeated freeze-thaw cycles. The data analyses also demonstrated a significant increase in the influence of density on the bond strength through time. This indicates that the importance of proper compaction during construction increases as the joint ages.

The results of this study suggest that scarification resulting from the portable asphalt recycling machine has the potential to improve patch performance compared to the saw-cut method of asphalt removal by increasing the bond strength of patch joints. Increased aggregate interlock between patch materials and original pavement can reduce joint faulting, decrease water ingress through the joint, and ultimately lead to improved patch durability that equates to reductions in overall pavement maintenance costs. The experimental patch section evaluated in this work was subjected to just one winter; further research should be conducted to evaluate the effects of scarification on long-term patch joint bond strength.

ACKNOWLEDGMENTS

The authors wish to express appreciation to Brandon Blankenagel, Dane Cooley, John Hema, Chris Parshall, and David Anderson of BYU for assistance with laboratory and field testing completed as part of this study. In addition, the authors recognize Derek Haynie, Tron Heralton, Jim Keller, Doug Angus, and Steve Christensen of Asphalt Zipper for providing equipment and materials necessary for the research. Gary Kuhl of the Utah Department of Transportation assisted with FWD testing. Funding for the research was provided through a grant from the BYU Ira. A. Fulton College of Engineering and Technology.

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TABLE 1 Shear Strength and Density Results

Joint Type	Time of Sampling	Shear Strength (psi)		Density (pcf)	
		Average	Std. Dev.	Average	Std. Dev.
Saw-Cut	Before Winter	11.98	4.25	130.20	1.73
	After Winter	12.23	5.13	132.30	1.23
Scarified	Before Winter	14.35	4.58	130.12	1.12
	After Winter	12.65	5.59	131.56	1.15

FIGURE 1 Portable asphalt recycling machine.


FIGURE 2 Scarified vertical pavement face.

FIGURE 3 Testing site after asphalt removal.

FIGURE 4 Compaction of patch material at test site.

FIGURE 5 Removal of asphalt core specimens.

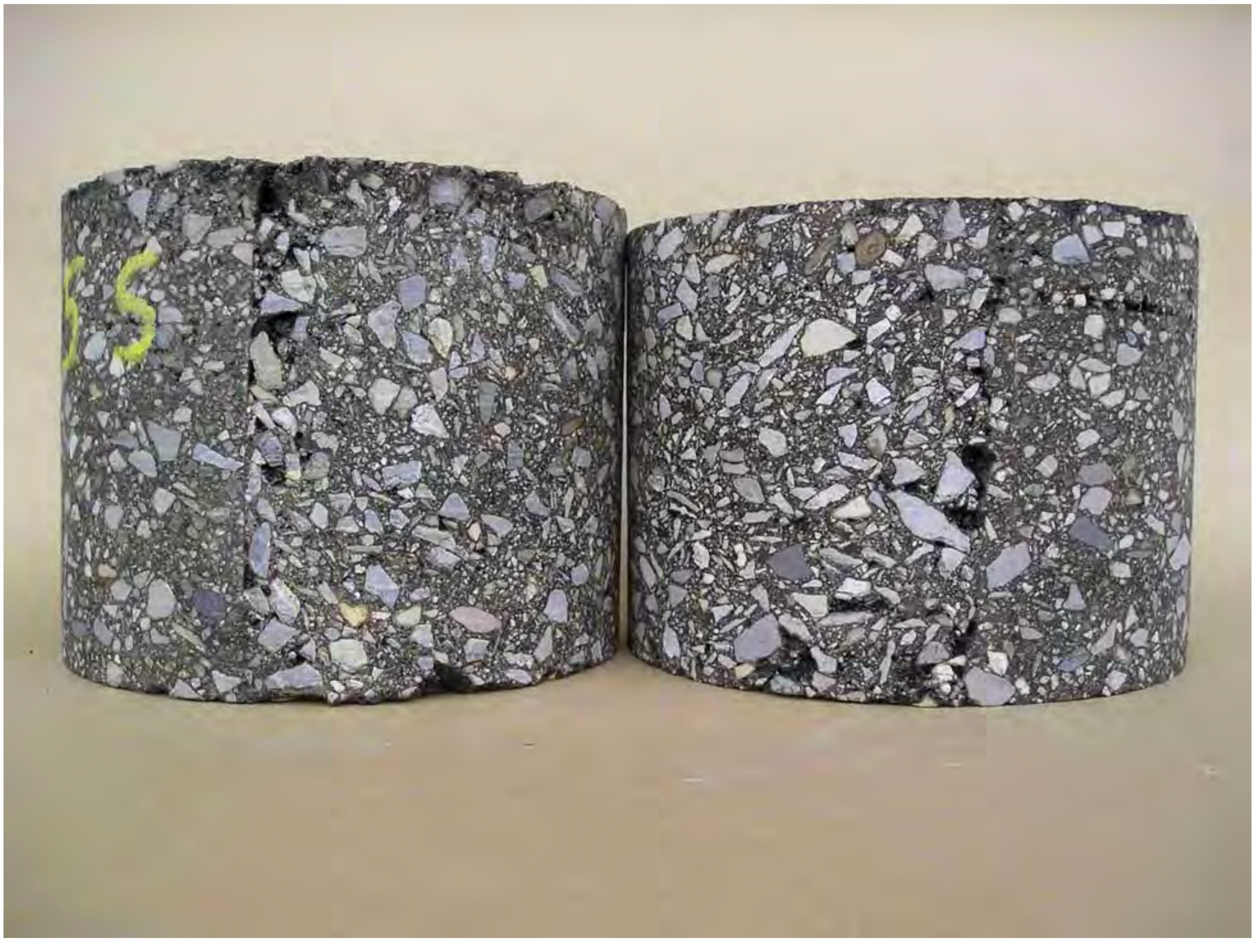
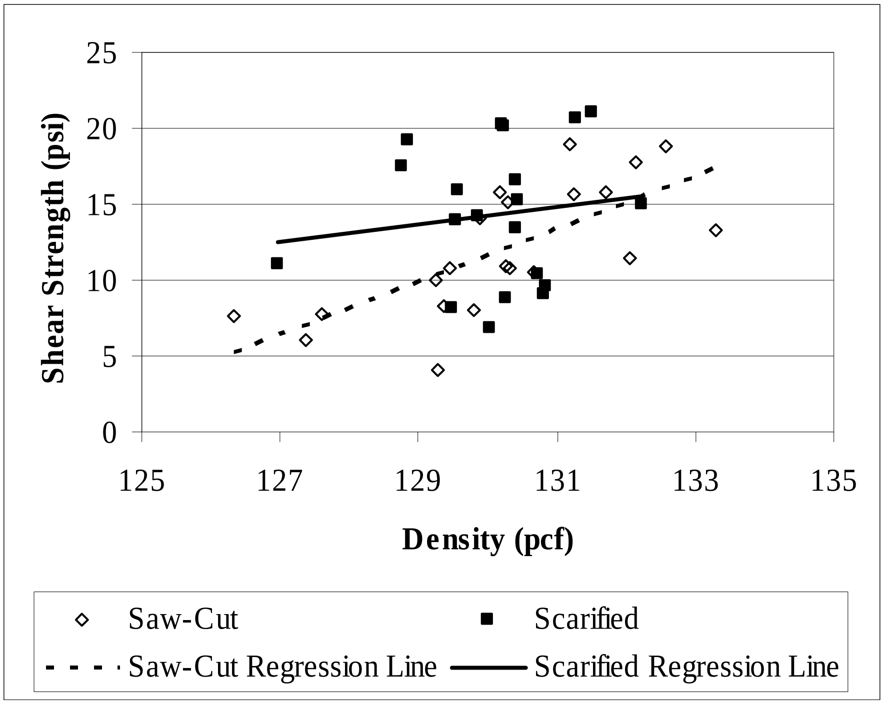


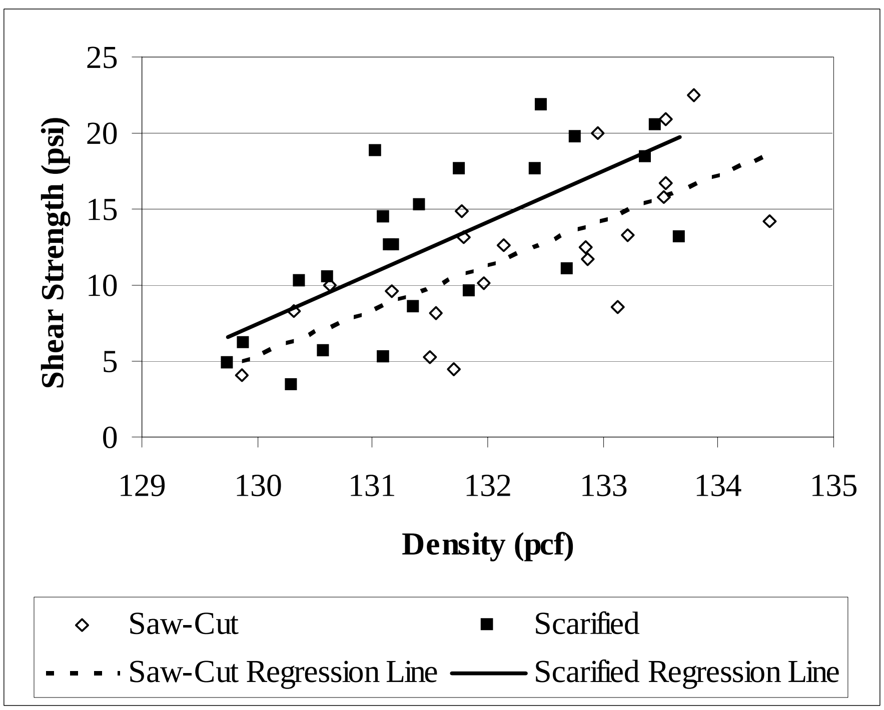
FIGURE 6 Typical cores from saw-cut joint (left) and scarified joint (right).

FIGURE 7 Shear testing of core specimens.

FIGURE 8 Joint evaluation with falling-weight deflectometer.

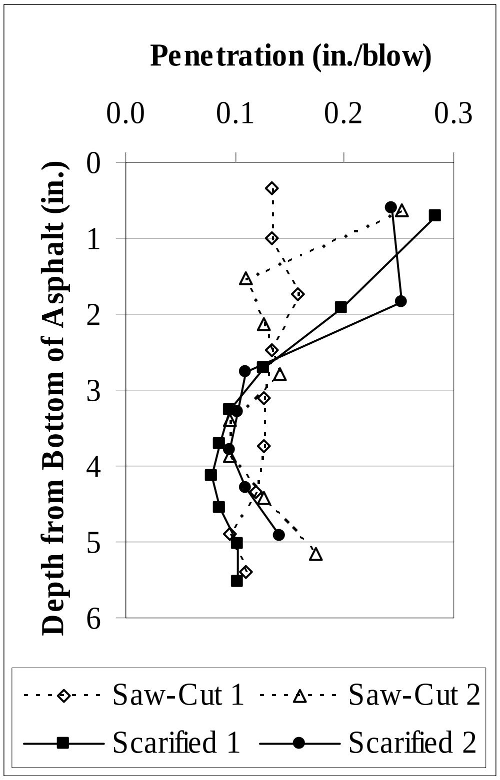


(a) Before winter.

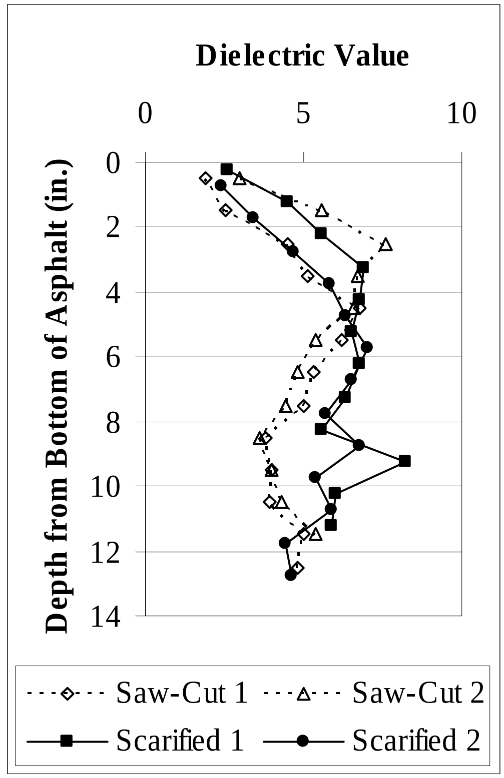


(b) After winter.

FIGURE 9 Relationships between shear strength and density for cores sampled (a) before winter and (b) after winter.



(a) Stiffness profile.



(b) Dielectric profile.

FIGURE 10 (a) Stiffness profile and (b) dielectric profile of aggregate base layer.

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