DEVELOPMENT OF A SLUMP-BASED WORKABILITY TEST FOR BITUMINOUS MAINTENANCE MIXTURES

Revised version submitted for inclusion in

TRB Annual Meeting Compendium of Papers CD-ROM
85th Transportation Research Board Annual Meeting
Washington, D.C., January 22-26, 2006

on

November 21, 2005

by

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Word Count: 7,968 (including 10 figures)
ABSTRACT
Although several tests have been devised to quantify the workability of bituminous maintenance mixtures, a better test method is required which evaluates the fundamental material properties affecting workability, shows correlation with field workability, is inexpensive and less labor and time intensive. This paper describes the development of the cold patch slump test (CPST), a slump based laboratory workability test for cold mix, which provides a measure for cohesion and internal friction which are intrinsic material properties affecting its workability. These material properties incorporate variables like binder content and aggregate gradation which affect cold patch workability. The inverse of slump time from these tests indicates a quantifiable workability measure. A laboratory subjective test was also developed and workability in the laboratory and field for six different containerized materials were compared, at different temperature levels.

Keywords: Bituminous maintenance mixtures, slump test, cold patch workability
INTRODUCTION
Workability is defined as the ability of a mixture to be handled and the ease with which it can be placed in field. It is an essential performance related property, especially for maintenance mixtures. Cold patching materials are used as a temporary measure for repairs during cold and wet weather. They are usually expected to last up to six months depending upon availability of hot-mix materials. This time frame of up to six months varies also according to the need for patching, and usually results in storage of maintenance mixtures in stockpiles.

Workability of the mixture prior to placement in field and over time in a stockpile is a critical issue in ascertaining the efficacy of the mix. If the mix is overly stiff it is extremely difficult to work with and may result in improper compaction, resulting in poor in-situ performance in the field. On the other hand, a mix which is very workable could result in poor stability under the action of traffic induced pushing or shoving. The stiffness or workability of a mix is influenced by a number of factors including the binder content of the mix and the temperature at which it is placed in the field. A mix with a high binder content and placed at higher temperatures would be relatively more workable and vice versa. Another concern specifically for stockpiled mixtures is the evaporation of the volatiles in the binder and the drain-down phenomenon. Both result in a stiffer mix thereby reducing the mix workability. Other factors affecting workability include aggregate gradation and cohesiveness between the binder and aggregate.

This paper focuses on the development of a laboratory test to evaluate workability of bituminous maintenance mixtures. Emphasis is placed on the parameters that affect mix workability and an effort is made to work towards identifying workability indicators from the test, in terms of the mix properties. In the past, several laboratory workability tests have been proposed but almost all of them have suffered in correlating results with field workability or are too cumbersome to conduct in the laboratory. To deal with these issues, an attempt is made to develop a test that is simple to perform in the laboratory, is less time consuming, and generates pertinent results.

The paper lists different workability tests that have been conducted in the past on cold patching materials, hot-mix asphalt mixtures, and concrete. Shortcomings of the various tests when applied to cold patching materials are identified and a cold patch slump test is proposed for evaluating workability. The CPST apparatus, procedure, and the experimental design are discussed. Slump tests using the CPST procedure were performed on six different commercially available cold patch mixtures. In addition, the objective measure of workability determined in the laboratory using the CPST is related to subjective assessments of workability both in the laboratory and in field. Results of the testing are reported and discussed followed by conclusions regarding measures to be adopted for future testing.

CURRENT WORKABILITY TESTS
In the development of a workability test for cold mix a number of different tests used to evaluate workability of different materials were investigated. This section describes workability tests used to assess bituminous cold patch, hot-mix asphalt, and concrete. Test procedures are outlined briefly and shortcomings of these tests with regards to testing of cold patching mixtures are identified.

Bituminous maintenance mixtures
The penetrometer test (I) was one of the first attempts to quantify workability of bituminous maintenance mixtures. The mix is compacted using two blows of a Marshall hammer in a Marshall mold at ambient temperatures. A concrete penetrometer (Soil Test CT-421) is used to measure the maximum force required to penetrate the surface of the molded mix. A subjective rating of good, fair,
or poor is associated with the mix. The mix is cooled to -6.7°C (20°F) and its ability to be broken apart with a spatula, having a blade length of approximately 203mm (8 inches) is assessed. Higher penetrometer readings were noted as the subjective workability declined. The data were inconsistent and a vane-shear device to measure maximum torque was proposed.

The Pennsylvania Department of Transportation (PennDOT) workability test using the 8 in spatula was extended by judging the subjective workability in the laboratory at -7°C (20°F), -1°C (30°F) and 4°C (40°F) (2). Three levels of workability were identified: “strong pass”, “pass”, and “fail”. The workability increased as the binder content in the mix increased, however for a couple of mixes an opposite trend was observed. It was concluded that binder content plays an important role in assessing mix workability. The subjective workability in the field was evaluated on the basis of the ease of breaking of crust and placement in the pothole. Similar levels of workability as in the laboratory were chosen, but no correlation with laboratory workability was investigated.

The Strategic Highway Research Program (SHRP) workability test (3) was devised to quantify workability and develop an acceptance testing procedure for cold patching materials. The test consists of a workability box, a pocket penetrometer (like Soiltest CL 700-A), and a penetrometer adapter. The workability box measures 102 mm on all sides and has a 10 mm hole in the center of one side panel. The adapter would increase the penetrometer diameter to 9.5 mm. Three samples of approximately 2500 grams each are cooled to 4°C. Each cooled sample is placed loosely in the workability box and the penetrometer with adapter is pushed through the hole to record the maximum resistance as an indicator of workability. Average of the resistance values from the three samples gives values between 0 and 5. The acceptance criteria define values less than 3 as acceptable, between 3 and 4 as marginal, and above 4 as unacceptable.

During a study evaluating performance of bituminous maintenance mixtures (4), the workability values using the SHRP test, fell below 1 for most of the mixes with some up to 2. As a result, modifications in the SHRP test were sought to better distinguish between the levels of workability of the different mixes. In the first modification, the hole located in the center of a side panel of the box was moved to the bottom third portion of the side panel. This modification resulted in slightly higher workability ratings for most mixes, but still could not distinguish well between the levels of workability of the different mixes. Most of mixtures had workability values below 1 and some up to 3. A second modification was made whereby the workability box was eliminated and standard size coffee cans were used to speed up the testing process. The material was placed loosely in the coffee can and stored at 4°C overnight to allow for consolidation prior to testing. Greater differences in workability values between different mixtures were noted; however correlation with field ratings of workability was not good. The Texas gyratory compactor was also used to quantify workability. The number of revolutions of the mold required to achieve specified pressures for compaction (Tex-206-F) was noted. The idea used was that a mix requiring lesser number of gyrations was more workable. Correlations between laboratory workability from either of the tests and field evaluations of workability were not good. Thus, no conclusive relationship was established between the quantitative laboratory measurements of workability and the subjective field ratings of workability.

The Texas triaxial test (Tex-117-E) was modified to evaluate workability of hot-mix cold laid (HMCL) maintenance mixtures by Estakhri and Button (4). Different confining stresses were applied and corresponding Mohr circles were drawn. The Mohr failure envelope was then plotted for the different mixtures. A failure envelope acceptance region was defined for both oven-aged and unaged HMCL mixtures. An alternative unconfined compressive strength test was also proposed as a measure of workability. Both, the modified triaxial test and the unconfined compression tests were
implemented for evaluation of HMCL paving mixtures (5). The apparatus for both tests require expensive equipment and cannot be readily conducted both in the laboratory and in field.

As per an American Society for Testing and Materials (ASTM) standard, workability of asphalt cold mix patching material was defined as the average maximum resistance to penetration by a designated penetrometer into a compacted asphalt cold mix that is confined in a designated box (6). This standard is applicable for stockpiled and containerized material, subjected to different climatic conditions. About 2 kg of material is placed in a box 165 mm × 165 mm × 50 mm, and compacted by two blows of a compaction hammer as per ASTM D 5581. The compacted specimen would have a height of 48 to 50 mm. The compacted material and box is placed at -10 ± 1°C for a minimum of 12 hours but no longer than 24 hours. A penetration blade (130 mm × 50 mm × 3 mm) is attached to the adapter at the bottom of a proving ring of Marshall apparatus with the blade parallel to the front of the machine. The box with compacted material is transferred from the freezer to the loading jack under the blade on the support stand. The motor is turned on and the upward movement of the jack head is continued. The highest dial reading is noted during 30 seconds of penetration. A similar procedure is adopted for two more specimens and the average reading is designated as workability of the mix. Precision and bias for this test is currently being investigated.

Hot-mix asphalt (HMA) mixtures
The idea of a workability meter, measuring the torque required to rotate a paddle immersed in a HMA sample, at a constant rotational speed, was developed in the 70’s (7). Workability was defined as the resistance moment (torque) produced by the mix against the blade rotation. Thus, workability is inversely proportional to the torque required to rotate the paddle within the HMA sample. The initial concept for workability device was developed by Instrotek, Inc., 1998. It utilized a Hobart mixer and an amp meter. The mix was placed within the Hobart mixing bowl and a dough hook was used to push the HMA within the bowl. The amperage required to keep the dough hook traveling at a constant speed, while pushing the mix within the bowl, was measured. This amperage was later converted to torque. Modifications to the original workability device were made to identify the change in workability due to changes in mix characteristics (8).

It was concluded that the workability of HMA was affected by the aggregate type. Mixes prepared with a cubical, angular granite were less workable (generated more torque at a given temperature) than mixes prepared with a semi-angular crushed gravel. The workability of HMA was affected by the nominal maximum aggregate size (NMAS) of the gradation. As NMAS increased for a given aggregate type, gradation shape, and binder type, workability decreased. Gradation shape did not have a significant effect on workability. Binder type significantly affected the workability of mixes. There was a relationship between workability and temperature that showed increased workability at higher temperatures.

A workability device as explained above was deemed inapplicable for cold patch workability for two reasons. Firstly, cold mix maintenance mixtures are much stiffer in nature than HMA mixtures and may generate high torque values or even damage existing equipment. Secondly, such cumbersome equipment cannot be installed readily in field, is expensive and the test is time consuming.

Concrete
A two-point workability device was developed to assess workability of soft-to-fluid fresh concrete (9). In the two-point workability device the torque required to rotate an impeller at a constant speed while submerged in the concrete is measured. The impeller, or paddle, is rotated at various speeds
and the corresponding values of torque are noted. The concept is similar to the workability device for HMA mixtures above. It was not considered for cold patch workability because it is an expensive and time intensive test.

The vibrating slope apparatus (VSA) was developed originally by the US Federal Highway Administration (FHWA) for measuring the workability of low-slump concrete. A modified energy-based approach, the International Center for Aggregates Research (ICAR) flow energy method, measures the minimum vibration energy to initiate concrete flow and the rate of flow at a given energy \(10\). The energy-based approach was developed to characterize the workability of dry-consistency concrete. Dry-consistency concretes do not readily flow under their own weight without vibration and behave more like solids than liquids. The chute angle of the apparatus was related to shear stress and the mass flow rate was related to the shear rate. The parameters determined from the test were the energy to initiate flow and the flow rate at a particular energy. It was observed that the ICAR flow energy method was able to distinguish between different levels of workability. Also, it could distinguish between different mixtures having same slump. However, a few problems suggested include, the size of the apparatus, and control over the displacement amplitude which could lead to large variations in energy values. The ICAR flow energy method parameters also need to be related to the field placement conditions.

The VSA apparatus was explored for workability of cold patching mixtures, since these are also dry and stiff. However, cold patching mixtures are more cohesive than concrete due to the presence of binder. Besides, flow due to vibration does not simulate the flow of the material or workability in field, for cold patching materials. A laboratory test involving compaction of material prior to flow assessment was considered more appropriate to judge the cohesiveness of the mixture. Both the cohesiveness and the aggregate interlock influence the mixture workability or flow capability.

The modified slump test was developed for measuring the yield stress and plastic viscosity for fresh concrete \(11\). The plastic viscosity parameter is related to the time required for the upper surface of concrete to slump 100 mm using a standard slump cone. The test is limited to concretes with slump of 120 to 260 mm. The validity of the test is required before being used as field quality control test. The test is simple to set up, operate, and can be conducted reasonably quickly. Given these factors it was explored further for evaluating the workability of cold patch as described in the following section.

**THE COLD PATCH SLUMP TEST (CPST)**

**Motivation**

A quick method applied at the Flexible Pavements branch of the Texas Department of Transportation (TxDOT) in Austin, to assess workability of patching materials, includes dumping a cold patch mixture, stored in five gallon buckets, onto a flat surface and noting the time it takes for the mixture (which takes shape of the container after dumping) to collapse under its own weight. This approach is similar to the slump test used extensively for concrete. A similar test using a standard slump cone was investigated. Patching material was placed in the cone and rodded as specified for concrete but it was found that the patching material would flow readily at ambient temperatures and it was impractical to measure the slump height. Based on the findings from these initial slump tests a modified cold patch slump test (CPST) was developed. The objective was to develop a test to assess workability in cold weather, when the maintenance mixtures are actually applied in field. Factors identified for consideration included degree of compaction, test temperature
and conditioning period. Different levels of compaction were used to assess the cohesiveness and the aggregate interlock of the mixture, and the inverse of the time to slump under its own weight was identified as a quantifiable measure of workability. More time to slump indicates lesser workability of the mix and vice versa. Described below is the apparatus and test procedure as developed.

**Apparatus**

Cylindrical specimens were prepared in polyvinyl chloride (PVC) tubes of 4-inches diameter and 10-inches height. PVC end caps, having diameter of 4-inches, were placed on one end of the tubes. A non-stick coating spray was sprayed on the inside of the mold as a bond breaker. A steel chute was used for pouring the material in the mold, utensils for transferring, and a balance (12) for weighing. A standard Marshall hammer (13) was used for the compaction. A standard measuring tape was used for determining the height of the compacted specimen. The conditioning of the specimens was done in a temperature control chamber, capable of maintaining temperatures from 1.7°C (35°F) to 23.9°C (75°F). The specimen extractor in a Superpave gyratory compactor was used to extrude the compacted specimens from the mold.

In addition to the slump tests, the procedure as developed involves the subjective rating of the cold patch. A wooden containment unit 24-inch × 24-inch with a cylindrical cavity 16-inch in diameter and ¾-inches in height was built for this subjective assessment in the laboratory. The volume of the cylindrical cavity was taken approximately equal to the volume of compacted specimen, with a height of ¾-inches, which is twice the maximum aggregate size of 3/8-inches. The specimen was placed in the cavity and allowed to fail. After failure, a standard 8-inch long and 1¼ inch wide spatula was used to work the specimen and fill the cavity. The CPST apparatus is shown in Figure 1 below.

**FIGURE 1 Apparatus for the CPST.**

**Procedure**

A mass of material necessary to prepare 8 ± ½ inch high specimens after compaction was used. A PVC cap was fitted to the bottom end of the tube and the inside of the mold was sprayed with a non-stick coating. A steel chute was used to pour the material in the mold. The specimen was compacted
in two lifts to ensure proper compaction, with half of the material compacted in the first lift. For each lift, the specimen was pre-compacted for 10 seconds by resting a Marshall hammer on top of the material. Thereafter, a specified number of blows of the hammer were applied. During compaction, special care was taken to make the surface of the specimen as level as possible. To ensure a level top surface, a metallic disc, 4 inches in diameter was placed on top of the material, during the second lift, and the hammer was placed on top of the disc. The disc was removed after compaction.

All the specimens were prepared at room temperature of about 25°C (77°F). The material was also at room temperature and was taken directly from bags of containerized patching materials. The final specimen dimensions were 4-inches in diameter and 8 ± ½ inches in height, keeping the aspect ratio close to 1, so the specimen does not fail due to toppling. After preparation, the specimen was sealed by placing a second PVC cap on the open end of the PVC tube and placed in a temperature control chamber, at a specified temperature, for 24 hours. After 24 hours, the specimen was extracted from the mold, using the extractor in the Superpave gyratory compactor. The extracted specimen was placed in the cylindrical cavity of the wooden containment unit and the time for the specimen to slump was recorded. Since the specimens were conditioned at low temperatures and tested at room temperature, the researchers were concerned about the rise in temperature of the specimen before slump. The surface temperature was recorded every 2 to 5 minutes and the center of the specimen temperature was noted after slump, using a handheld temperature gun.

Once the specimen failed, a rater filled the cavity with the material using a standard 8 inches long spatula. The time required to fill the cavity was noted as one measure of (subjective) workability. Secondly the rater provided a subjective rating of the material workability based on a scale of 1 to 5, where 1 meant the material was easiest to work and 5 meant the material was hardest to work.

Development of experimental design
The experimental design consisted of three variables namely, material type, compaction effort, and conditioning temperature. The material type had a total of six levels based on the six different containerized cold patching materials evaluated as a part of this study. These materials were labeled A through F in this study. Compaction effort was defined on the basis of the number of blows per lift of the standard Marshall hammer. Conditioning temperature had three levels, 1.7°C (35°F), 12.8°C (55°F), and 23.9°C (75°F), thereby covering the typical temperature range of cold mix patching material, when placed in the field.

Initially as a part of a pilot experiment each of the six materials were tested after conditioning at the different temperature levels. Compaction effort was varied with levels of 0, 1, 5, 10, and 20 blows per lift. Zero blows per lift symbolized only 10 seconds of static load of Marshall hammer on top of each lift. A fixed mass of the material for each type was taken initially, and depending upon the final specimen height attained, an estimate of bulk specific gravity was calculated and the appropriate amount of material required to attain an 8-inch final specimen height was calculated.

On the basis of the results from pilot experiments, it was decided that compaction effort be limited to two levels i.e. 5 and 10 blows per lift, because there was too much variability in slump times for specimens compacted with less than 5 blows per lift and would take considerable time (up to two hours) if more than 10 blows per lift were applied. After the failure of each specimen, a subjective assessment was made by a rater and the time to fill the containment unit was noted.

Upon completion of the above experiment a pilot experiment was initiated to assess the use of weights placed on the specimens to accelerate the testing. Slotted metal weights of 0.9 kg (2 lbs),
2.26 kg (5 lbs), and 4.53 kg (10 lbs), 4-inches in diameter, were placed on top of the specimens to reduce the time to failure for different materials. Materials C, F and D were chosen since they represent the low (few seconds), medium (few minutes), and high (few hours) times to failure under their own weight, respectively. Specimens were prepared at 10 blows per lift and conditioned at 35°F, representing the severest condition.

During the period of February 2005 to April 2005, all six materials were installed in the field under cold (39°F to 47°F), warm (49°F to 63°F), and hot (66°F to 81°F), material temperatures. The subjective workability ratings under different material temperatures were compared later with the laboratory workability measures under similar temperatures of 35°F, 55°F, and 75°F respectively.

RESULTS AND DISCUSSION
The gradation curves of the different materials used in the experiment are shown in Figure 2. Material F has a fine gradation, materials C and E are open graded and the other materials are dense graded. The residual binder content in the materials A, B, D(new), and D(old) is between 4.5% and 4.7%. Material C and E have residual binder contents of 3.5% and 5% respectively. All the materials have percent fines, passing sieve # 200, between 1.5% and 4.8%.

![Gradation curves for various materials.](image)

Laboratory workability assessment was performed for compaction efforts of 5 and 10 blows per lift. Figure 3 compares the objective measure of workability determined as the time for the prepared cylinder to slump under its own weight with the subjective measure of the time it takes to fill the containment unit after the material has slumped. All six containerized materials A through F were tested, with some replicates, at the three different temperature levels. From the figure it can be observed that there are deviations from a linear relationship due to the fact that some of the materials, although having a high slump time, are easy to work in the containment unit. Thus, effort put in by
the rater, different aggregate type and gradation results in variation in the time to fill the containment unit.

**FIGURE 3 Laboratory workability assessment at 10 blows per lift.**

Figure 4 depicts the variation between the slump time and the subjective rating assigned by the rater after filling the containment unit. All six containerized materials A through F were tested, with some replicates, at the three different temperature levels. There is a uniform rise in rating with slump time for 35°F conditioning.

**FIGURE 4 Laboratory workability assessment at 10 blows per lift.**
Figure 5 describes the variation of the subjective measure of the time it takes to fill the containment unit with the subjective rating assigned by the rater. All six containerized materials A through F were tested, with some replicates, at the three different temperature levels. The r-squared values for 55°F and 35°F are 0.89 and 0.72 respectively. This suggests a positive linear correlation between the two subjective measures in the laboratory.

The inverse of the slump time suggests a quantifiable measure of workability. A material taking a long time to fail in slump will have less workability. Figure 6 shows the variation of the conditioning temperature with the inverse of the time to slump of the specimen under its own weight. As the conditioning temperature rises a material has increased workability. Material C has the highest workability and material D the lowest. The r-squared values range from 0.8 to 0.89 for the different materials, suggesting a positive linear correlation between the workability measure and temperature.
Correlation between subjective field measures of workability and the workability measures in the laboratory are essential for the validation of the laboratory tests. Figure 7 shows the variation of the subjective rating in field with the time to slump. At cold material temperature (39°F to 47°F in field and 35°F in laboratory), barring one point with high slump time and high field workability, there is a positive linear correlation with r-squared value of 0.69. The field subjective ratings depend on the crew person installing the patches and are highly variable between different installers.

The subjective rating in the field and the time to fill the containment unit, as per Figure 8, suggests that at warm material temperatures (49°F to 63°F in field and 55°F in laboratory), there is a positive linear correlation with r-squared value of 0.89.

The subjective ratings both in laboratory and field are on a similar scale of 1 to 5 with 1 being the easiest to work and 5 being the toughest to work. Figure 9 depicts the variation of the field subjective rating with the laboratory subjective rating. At cold material temperatures, the r-squared value is 0.77, and at warm material temperature it is 0.88. Considering the fact that the patching materials are usually installed in cold weather there is evidence to suggest that there is a positive linear correlation between laboratory and field workability.

A pilot experiment with weights on top of the specimens to accelerate the slump time was conducted. Figure 10 shows the variation of the weights placed on the specimens with the time to slump. It reveals a negative exponential correlation, with time decreasing as heavier weights are placed on the specimens. The r-squared value ranges between 0.932 to 0.943 for material F and D respectively. Material D has the highest slump times among all the materials, material C has the lowest and material F represents all other materials which have similar slump times and fall in between.
FIGURE 7 Workability assessment in field and laboratory.

FIGURE 8 Workability assessment in field and laboratory.
FIGURE 9 Subjective workability in field and laboratory.

FIGURE 10 Slump times for different materials with weights on top.
CONCLUSIONS AND FURTHER RESEARCH

This paper describes the development of a slump based workability test for bituminous maintenance mixtures. The CPST is an inexpensive, quick and simple test procedure used to quantify workability of bituminous maintenance mixtures in the laboratory. The application of a slump based test where the material is compacted and conditioned at temperatures similar to those encountered in field help to capture the ease in placement of cold patching material in the field. The inverse of the slump time indicates a measure of workability, and the results demonstrate a uniform increase in workability with material temperature. The variation of slump time with the subjective measures in the laboratory shows a positive linear correlation however the deviations are a result of different aggregate gradations and variability in effort exerted by rater. The laboratory workability measures and the subjective rating in the field show positive linear correlation in cold (39°F to 47°F) and warm weather (49°F to 63°F).

Material C having an open gradation, 3.5% residual binder, and 1.5% fines, took the least time to slump at 35°F or is the most workable at cold temperatures. Material D having a dense gradation with 4.6% residual binder took the most time to slump at 35°F, or is least workable at cold temperatures. Thus, binder content and aggregate gradation influence the workability of cold patching material.

There is strong negative exponential correlation between the weights placed on specimens and the time to slump, indicating that the next task would be to select an appropriate weight based on prior results and test all the specimens with that weight on top, to reduce the slump time.

The maximum rise in temperature on the surface of the specimen was about 10°F (for specimen taking two hours to slump) and the center of the specimen was within 2-3°F upon failure. The researchers concluded that the rise in temperature of the material would not contribute significantly to a reduction in slump time. The failure of the specimen is a combination of shear and normal stress acting on the failure plane. Intrinsic material properties like cohesion and internal friction influence the workability of the material. The stress calculations on the specimens undergoing slump shall help in estimating these parameters to comment on the workability of the material. These parameters incorporate variables like binder content and aggregate gradation, which affect the workability of maintenance mixtures. The slope of gyratory compaction curves and the work done due to shear during compaction are also being explored as potential measures of workability.

One rater has been used thus far for laboratory subjective workability measures, on all materials A through F. The experiment shall be expanded in the future to incorporate three or more raters, to reduce any statistical bias. Further tests on cured materials will help characterize the workability of cold patching materials taken from stockpiles.

ACKNOWLEDGEMENT

This research is sponsored by TxDOT. We express our sincere gratitude to the TxDOT project monitoring committee, especially the project director, Mr. Tracy Cumby, for their technical input during the progress of the project. We are grateful to the maintenance division crews of both Lubbock and Lufkin districts for their contribution in field installation and field subjective ratings of various containerized patching materials.

We appreciate the involvement of the following six cold patch manufacturers for donating material for this research project. They supplied the products used for testing which include (in alphabetical order) Asphalt Patch, Perma Patch, Proline, QPR, Stayput, and Unique paving materials (UPM).
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