NCAT Report 06-06

# DEVELOPMENT OF LABORATORY PROCEDURE FOR MEASURING FRICTION OF HMA MIXTURES – PHASE I

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# DEVELOPMENT OF LABORATORY PROCEDURE FOR MEASURING FRICTION OF HMA MIXTURES – PHASE I

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## INTRODUCTION

Pavement friction during wet conditions continues to be a major safety concern for pavement design and maintenance. Friction is defined as the relationship between the vertical force and horizontal force developed as a tire slides along the pavement surface. Its magnitude mainly depends on the pavement surface characteristics and vehicle characteristics. Vehicle characteristics, such as speed, braking system and tire condition are not within the control of the highway road engineer. However, the highway engineer should provide pavement surface characteristics with sufficient friction to meet the design criteria. The skid resistance of pavements is commonly measured using ASTM E 274, Skid Resistance of Paved Surfaces Using a Full-Scale Tire.

However, there are no standard test procedures for evaluating the friction of an HMA wearing course during the mix design process. There are two tests for evaluating the polishing properties of an aggregate: British portable skid resistance tester (ASTM Test Procedure D 3319-00 and E 303-93 [Re-approved 2003]), and the acid insoluble residue test (ASTM D 3042-03). As a part of the testing on Phase I of the NCAT test track, surface characteristic tests were conducted each month on all sections to evaluate the degradation of the skid resistance with traffic. The testing was conducted by the Alabama DOT using a skid trailer meeting the requirements of ASTM E 274. Figure 1 shows the average results of that testing for like mixtures (above restricted zone (ARZ), below restricted zone (BFZ), through the restricted zone (TRZ), stone matrix asphalt (SMA), and open graded friction course (OGFC).

It would be beneficial to develop a testing procedure and laboratory equipment that could be used to evaluate the frictional resistance of HMA mixtures in the laboratory that represents field measured results.

## OBJECTIVE

The objective of this study was to design and build a prototype laboratory device and develop tentative laboratory procedures for evaluating the wet friction and/or aggregate polishing characteristics of HMA mixtures.

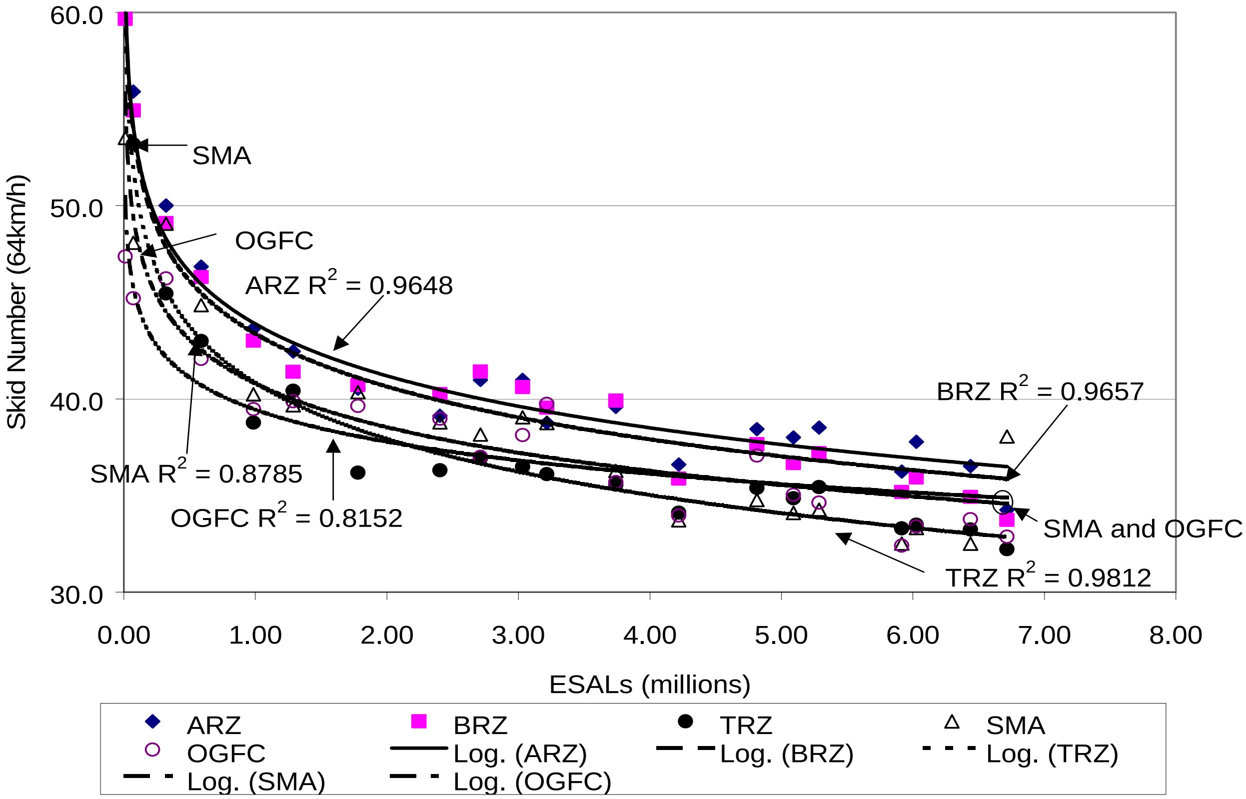


**Figure 1. Ribbed Tire Skid Number versus ESALs by Gradation Type (from data collect at NCAT Test Track)**

## TEST PROGRAM

The Japanese have developed a Dynamic Friction Tester (DF Tester) and Circular Track Meter (CT Meter) that can be used in combination to determine the International Friction Index (IFI) for an HMA pavement. The test procedures (as discussed below) for the two devices require a minimum surface area of 17.75 inches by 17.75 inches.

A prototype laboratory testing machine will be fabricated that polishes the surface of an HMA surface, using rubber tires, similar to the polishing that occurs on roadway surfaces due to traffic. The polishing of the prototype machine should provide a laboratory prepared sample surface, similar to that provided under service, that can then be evaluated using the DF Tester and the CT Meter.

### Dynamic Friction Tester

The Dynamic Friction Tester (DF Tester) (Figure 2) is specified by ASTM E 1911. The DF Tester has three rubber sliders that are spring mounted on a disk at a diameter of 350 mm (13.75 in). The disk is initially suspended above the pavement surface and is driven by a motor until the tangential speed of the sliders is 90 km/h (55 mph). Water is then applied to the test surface, the motor is disengaged, and the disk is lowered. The three rubber sliders contact the surface and the friction force is measured by a transducer as the disk spins down. The friction force and the speed during the spin down are saved to a file. The DF Tester can be used to measure the friction as a function of speed over the range of zero to 90 km/h (0 to 55 mph). The entire operation is controlled by software in a laptop computer. The DF test system can be used to measure friction characteristics of laboratory manufactured samples that are at least 450 by 450 mm (17.75 by 17.75 inches).

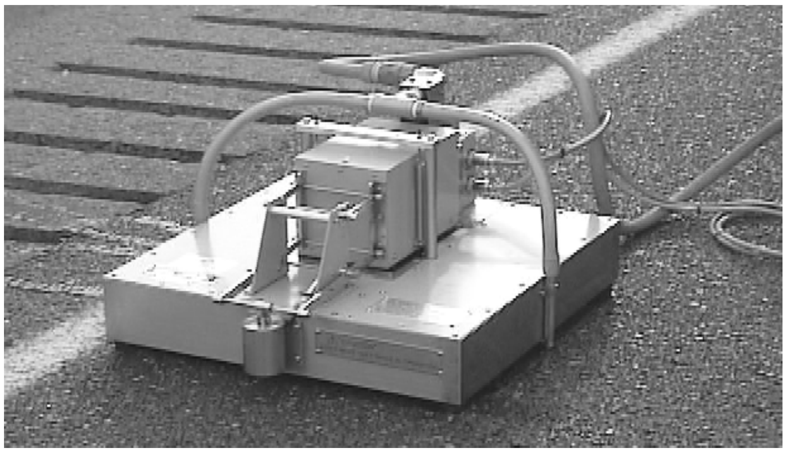

**Figure 2. Dynamic Friction Tester (DF Tester)**

### Circular Track Meter

Historically macrotexture has been measured using a volumetric technique. The technique consists of spreading a known volume of material (sand, glass beads, or grease) on the pavement and measuring the area covered. Dividing the volume of material used by the area covered provides the macrotexture depth or the Mean Texture Depth (MTD). This method is referred to as the "sandpatch" or "greasepatch" method. Originally the sandpatch method consisted of spreading a specified volume of Ottawa sand which passed the No. 50 sieve and was retained on the No. 100 sieve. The sand is spread with a spreading tool in a circular motion. The area of the circular patch of sand is determined by using the average of four equally spaced diameters. The current ASTM Standard E-965 calls for using glass spheres instead of sand. A variation of this method is used by NASA and is called the grease patch method in which the spreading material is grease.

Recent advances in laser technology have resulted in automated equipment that can be used to compute the profile statistics for a pavement surface. One such device is the Circular Track Meter (CT Meter) (Figure 3). This test procedure is presented in ASTM E2157. The CT Meter uses a laser to measure the profile of a circle 284 mm (11.2 in) in diameter or 892 mm (35 in) in circumference. The profile is divided into eight segments of 111.5 mm (4.4 in). The average MTD is determined for each of the segments of the circle. The reported MTD is the average of all eight-segment depths. The CT meter system can be used to measure the MTD characteristics of laboratory manufactured samples that are at least 450 by 450 mm (17.75 by 17.75 inches). The friction result from the DF Tester at 20 km/h (12 mph) along with the Mean Texture Depth

(MTD) measurement from the CT meter can be used to calculate the IFI of a laboratory manufactured sample.

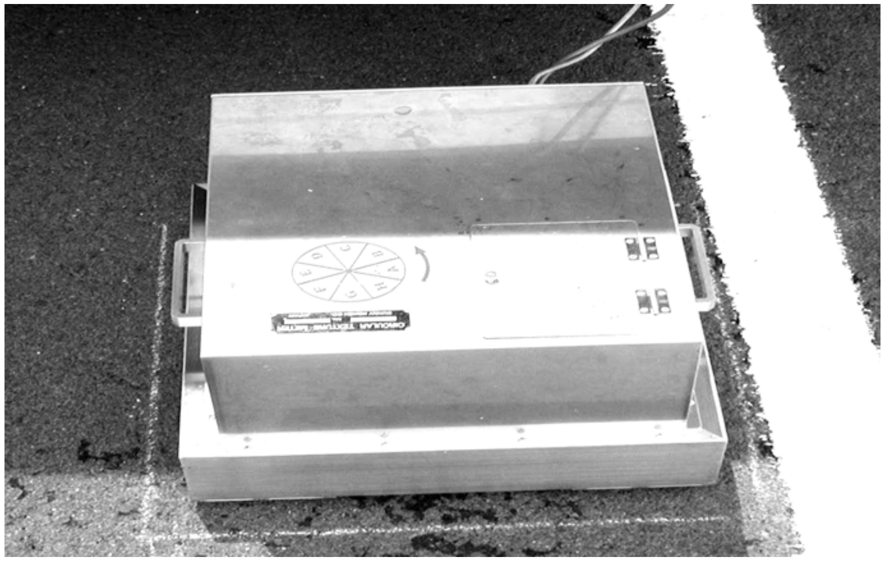

**Figure 3. Circular Track Meter (CT Meter)**

**Laboratory Preparation of HMA Test Surface**

The DF tester and CT meter were selected to evaluate the HMA surface condition before and after the polishing of a Laboratory prepared HMA surface. The prototype polisher, described latter in this report, was designed with three wheels that tracked and polished a circular path that matched the circular path used by the DF tester and the CT meter in their evaluation of pavement surfaces. A laboratory method of preparing different HMA pavement surfaces for evaluation had to be developed.

Two methods were investigated for making the HMA slabs for use with the polishing machine. One method used a walk-behind vibratory roller and the other used a modified Hamburg rolling wheel compactor. The walk-behind vibratory roller has been used in the past to produce large beams of HMA with good results. The standard rolling wheel Hamburg compactor has been used for constructing slabs to be used with the Hamburg rutting machine. However, the Hamburg slabs are smaller than the slabs needed for this investigation.

The slab size requirements for this investigation were a minimum of 17.75 inches by 17.75 inches. This is the minimum size that the CT Meter and DF Tester need to evaluate a slab surface for friction and texture. Both methods of compaction were investigated to determine which would be the easiest to control the slab thicknesses, surface texture, and HMA properties. A coarse-graded 12.5 mm Superpave designed mix was selected for the construction of the slab during the first phase of this study. The mix design gradation is shown in Figure 4.

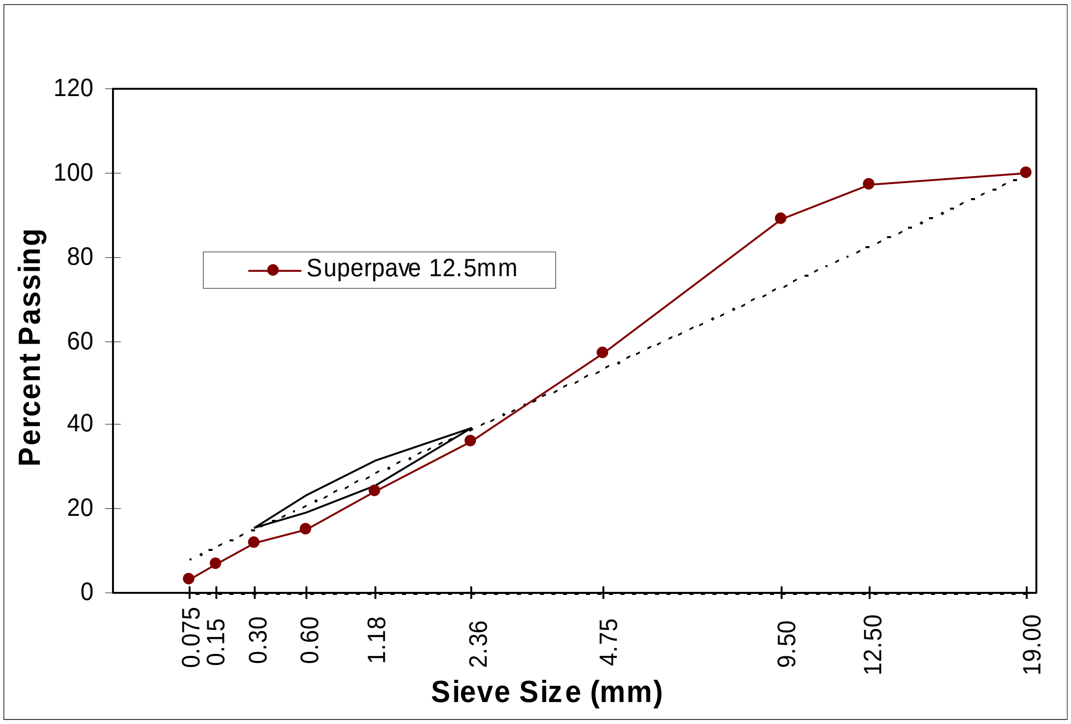


**Figure 4. Mix Design Gradation**

*Laboratory Mixing of the HMA*

A Hobart mixer, model number H600 (60qt.), was used to mix the HMA for the construction of the slab. The dough hook mixing blade supplied with the mixer (Figure 5) was used in the mixing process. The wire cage mixer (Figure 5) usually used for most HMA mixing was not strong enough to mix the heavy batch of HMA required for the slabs.

A granite aggregate was used in all the HMA mixes for this investigation. Aggregates were blended in batches to provide the design gradation shown in Figure 4. The HMA mix weight was calculated to produce a slab 3 inches thick, with the desired air voids of 6.0%

Each batch of aggregate was split and placed in two 5 gallon buckets for heating. PG67-22 asphalt cement was used for the binder. The asphalt cement was weighed placed in a gallon can for heating (weight of asphalt cement produced an asphalt content of 6%). The two 5 gallon steel buckets of aggregate to make up the total batch were placed in a 350°F oven overnight. This temperature and time was chosen to assure a constant temperature through out the aggregate before mixing. The gallon can of PG67-22 asphalt cement was heated to 310°F before mixing. The heated aggregate was placed in the mixing bowl as shown in Figure 6 and mixed for 15 seconds (dry mixing) before the heated asphalt cement was added.

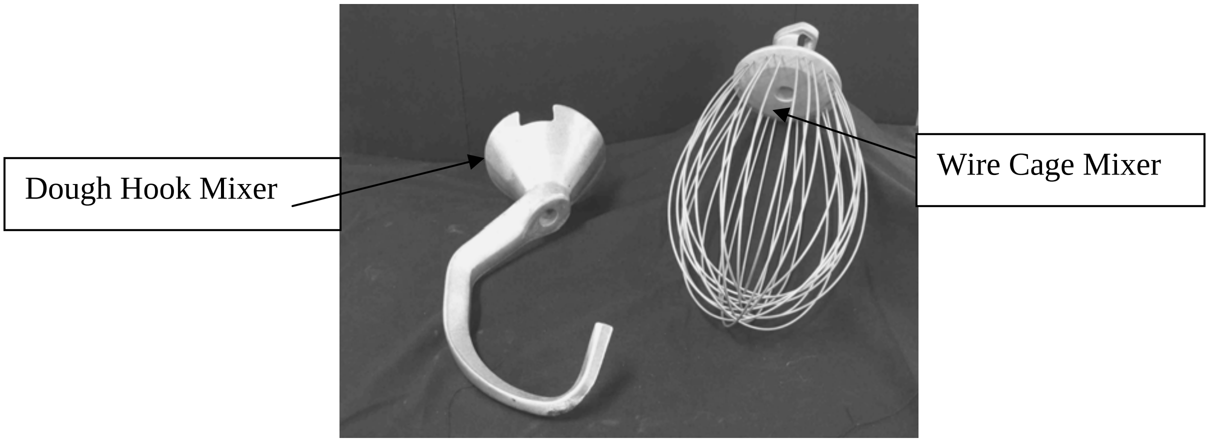


**Figure 5. Dough Hook and Wire Mixer**

**Figure 6. Mixing Aggregates Prior to Adding Asphalt Cement**

The dry-mixing of the aggregate at a slow speed (approx. 30 rpm) was found to help eliminate segregation and produce a more uniform mix when the asphalt cement was added. After dry mixing for 15 seconds, the 2,444 grams of heated PG67-22 asphalt cement was added to the mixing bowl while the mixer continued to mix at slow speed. After the asphalt cement was completely added to the mix, the speed of the Hobart mixer was increased (approx. 60 rpm) and mixing continued for approximately 45 seconds or until complete mixing was accomplished. During the 45 second mixing period, a long spatula was used to scrape the sides of the bowl to assure that any fines and/or asphalt cement stuck to the sides of the bowl were included in the total mixing of the sample. The mixing process described in this paragraph produced acceptable mixing of the HMA with minimal time required. From visual inspection the HMA produced had minimal segregation of the aggregate and showed little evidence of uncoated aggregate in the mix. Therefore, this mixing process and equipment was used to produce the HMA for all the slabs constructed during phase I.

*Two Methods Were Evaluated for Compaction*

Two methods were evaluated for compacting the mixture. The first method used was a walk behind vibratory roller and the second method utilized a modified Hamburg rolling wheel compactor.  The best method was selected for compacting the remainder of the samples.

*Method 1.  Compacting Slab Using Walk-Behind Vibratory Roller.*  A metal frame to confine the mixture during compaction was constructed using a 3.25 inch square metal beam. The metal beam was cut in lengths so the lengths could be bolted together to form a 24 inch square (inside dimensions) frame which was used to confine the HMA sample during compaction (Figure 7).

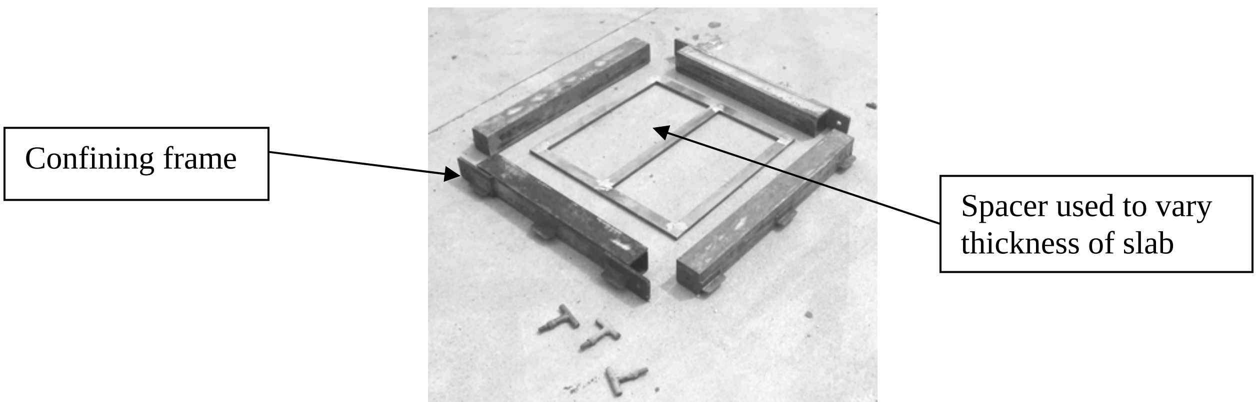


**Figure 7.  Frame and Spacer**

Spacers frames were constructed 24 inches square by 0.25 inches thick (see Figure 7) so that the compacted thickness could be varied by intervals of 0.25 inches. A solid steel plate 24 inches square by 0.25 inches thick was used as the base to compact the mix (Figure 8).


**Figure 8.  Square Mold (24" by 24") with Solid Base Plate**

Using the spacers and the base plate, the thickness of the constructed slab can be varied by intervals of 0.25 inches from 3 inches thick to 0.25 inches thick. A double drum vibrator walk-behind roller (BOMAG BW65H) was used to compact the slab sample in the mold (Figure 9). The two drums of the BW65H roller were 22 inches wide.

The mixing process described previously was used to mix the HMA sample for placement in the mold. The area where the compaction process took place was approximately 75 yards from the mix area. A wooden platform was constructed around the steel form to facilitate the compaction (Figure 9).

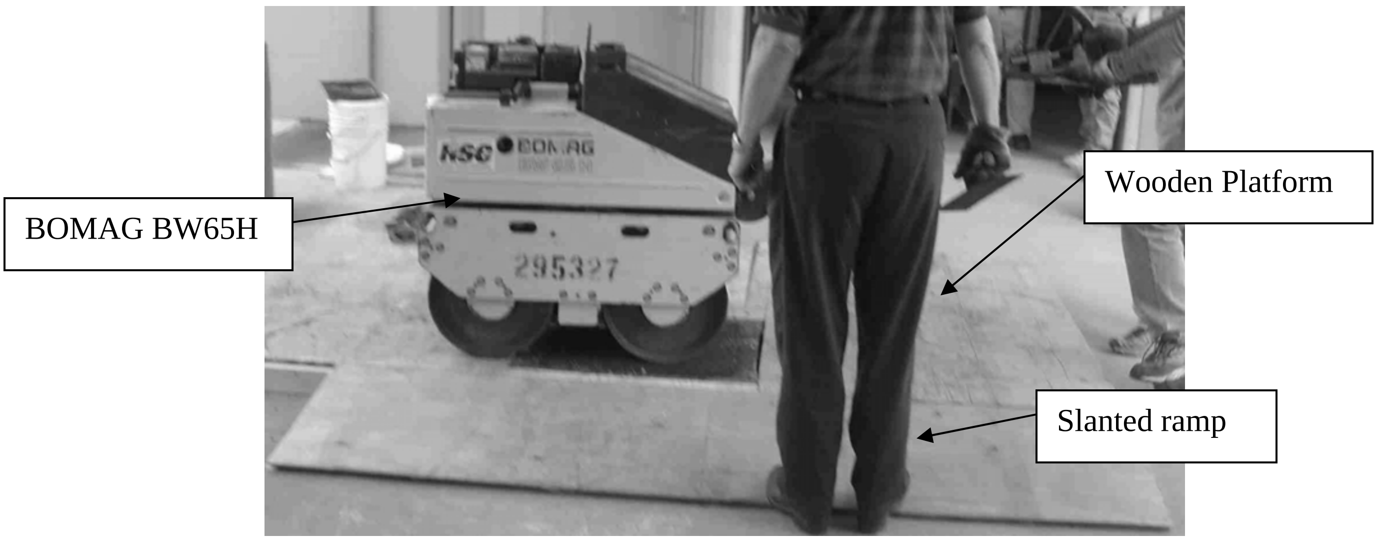


**Figure 9. Wooden Platform Constructed Around Mold**

The HMA was transported in the mixing bowl by cart to the compaction area. Transportation of the HMA took approximately 5 minutes The HMA was immediately placed in the center area of mold. The HMA was then pushed out to the corners and smoothed out using a 4 inch by 14 inch rectangular trowel (Figure 10).

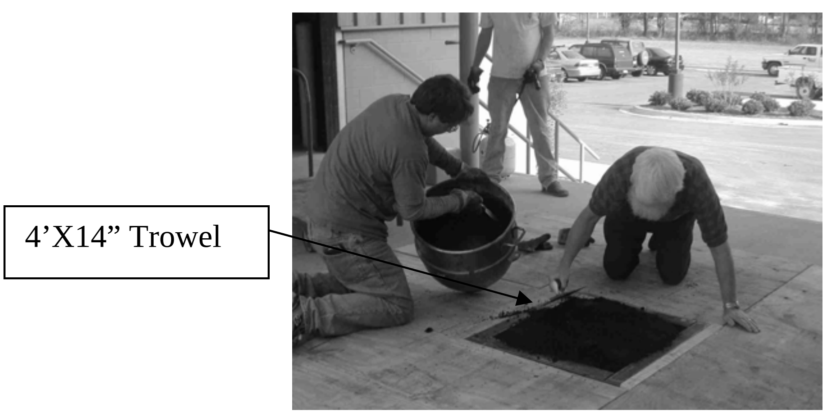


**Figure 10. Distributing Mix Evenly in Mold**

Particular emphasis was placed on minimizing segregation and maintaining uniformity during the spreading and smoothing out of the mix in the mold before compaction started. The placement of the mix in the mold took another 10 to 15 minutes allowing an additional cooling period. The differential cooling and segregation of the mix during the placement process was difficult to control.

The HMA was then compacted using the walk-behind BOMAG BW65H vibratory roller (Figure 9). The width of the roller drums were approximately 2 inches less than the inside dimensions of the mold making it difficult to maintain surface smoothness and prevent movement of material around in the mold. During rolling, one edge of the roller would roll on the surface of the metal frame causing the other edge to dig into the mix surface which resulted in tears and unevenness of the surface. The vibratory roller would shove mix in front of the roller and over the sides of the mold.

The material had to be removed from the edges of the mold constantly in an effort to maintain surface smoothness on the slab. The removal of this material affected the weight of mix being placed in the mold to obtain designed air voids with the constructed thickness. The movement of material caused roughness and variable densities and surface texture in the slab. In order for the process to be successful a wider roller to completely span the 24 inch width of the mold was needed. Also a redesign of the mold to prevent the mix from being shoved out of the mold during the rolling process was needed. Construction of the HMA slabs using the vibratory rolling technique were discontinued due to the problems encountered.

*Method II. Compacting Slab Using the Modified Hamburg Compactor*. The standard Hamburg compactor was designed to construct a slab11 inches by 15 inches which is the required size for use in the Hamburg rutting and moisture tester. The thickness of the slab can be varied in ¼ inch increments from 1/2 inch to 4 inches. The original rolling wheel used to compact the Hamburg slabs was 12 inches wide. Modifications to the compactor were necessary in order to compact a minimum size slab of 17.75 inches square for use with the CT Meter and DF Tester. The frame of the Hamburg compactor was cut and widened to allow the 12 inches wide rolling wheel to be replaced with a 21 inch wide roller (Figure 11).

**Figure 11. Modifications to Frame and Roller of the Hamburg Compactor**

A new platform was constructed to accommodate the mold for the compaction of the larger slabs (Figure 12).

**Figure 12. Larger Platform to Compact Slabs**

A new mold was fabricated to be used to construct a 20 inch square slab (Figure 13).

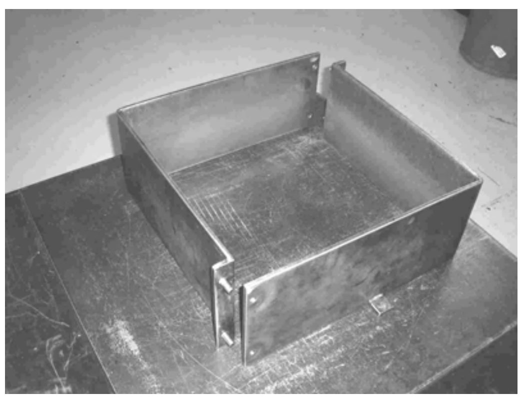

**Figure 13. New 20" by 20" Mold for Hamburg Compactor**

Spacers similar to those shown in Figures 7 and 8 were placed in the mold to obtain the desired slab thickness. Four by twenty inch steel plates were placed vertically on top of the HMA in the mold and perpendicular to the path of the roller as shown later. Both 3/8 and 1/8 inch thick plates were used to cover the slab before compaction. During compaction, the steel wheel roller moved across the top of these plates putting pressure on each individual plate. This resulted in a kneading action during compaction without shoving and/or moving the mix in front of the roller. The modified Hamburg compactor is shown in Figure 14.

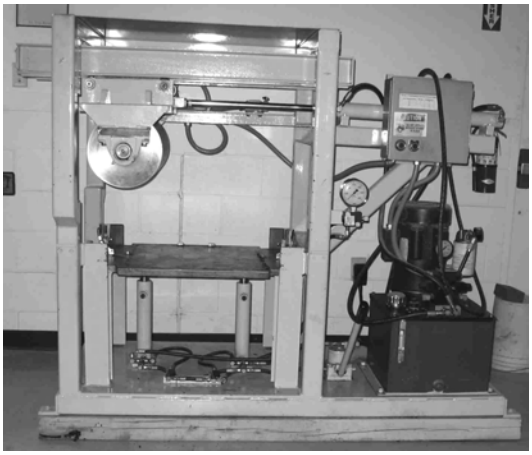

**Figure 14. Modified Hamburg Compactor**

The mixing process described previously was used to mix the HMA sample for placement in the mold. The Hamburg compactor and the Hobart mixer were adjacent to each other; therefore the cooling of the mix during transportation from mixing to compaction was minimized. Trials were conducted to determine the best procedures to follow during the construction of the slab. The following procedures for the construction of the slabs were established as a result of the trials. After mixing, the HMA was dumped in the middle of a 1/2 inch thick iron sheet measuring 36 by 36 inches. The iron sheet was pre-heated using a blow torch in order to minimize heat loss in the HMA when placed on the plate. The HMA pile was then quartered using a quartering tool as shown in Figure 15. Separation paper was placed in the bottom of the mold to prevent the compacted HMA from sticking to bottom of mold.

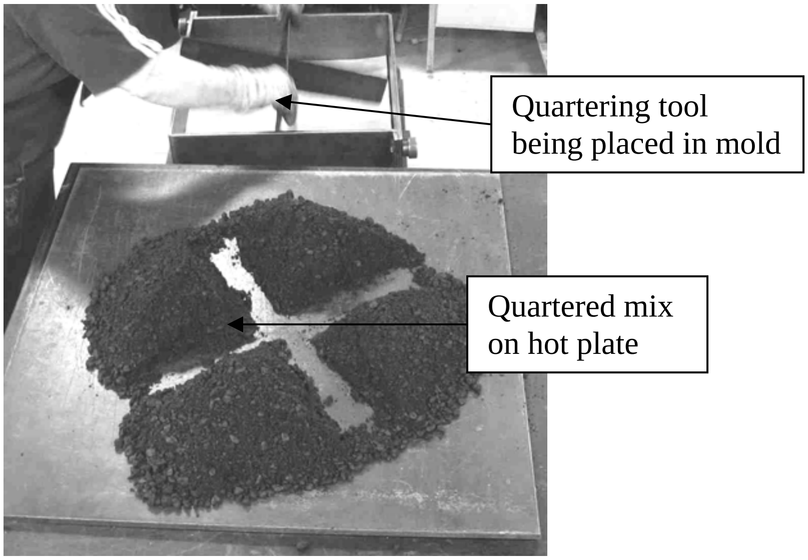


**Figure 15. Quartering Mix Using Tool**

The quartering tool was then removed and placed in the mold so that each quarter of the pile of HMA could be placed in a quarter of the mold for spreading (Figure 15). Once the HMA was placed in the four quarters, the quartering tool was removed and the mix spread evenly. The placement and spreading of the HMA was done in quarters to minimize segregation of the HMA during this operation. Once the HMA was spread evenly in the mold, a separation paper was then placed on the un-compacted mix in the mold. Plates measuring 3/8 inches thick 4 inches high and 20 inches long were then placed in the vertical position on top of the mix (Figure 16) until they completely covered the mix and were fairly tight.  The tightness of these plates was determined with experience. Basically, the plates needed to be tight enough not to wobble during rolling and not so tight as to prevent independent movement up and down of the individual plates during rolling.

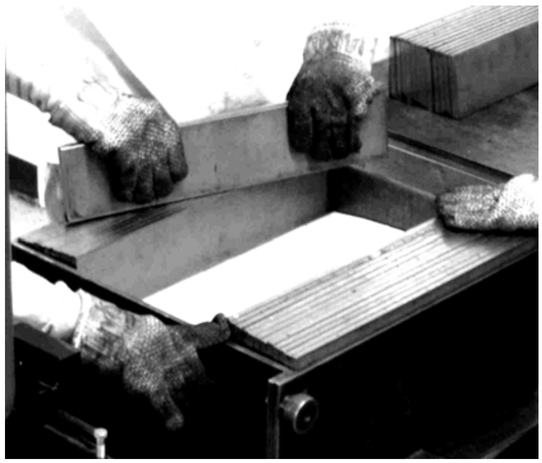

**Figure 16.  Placing Plates Vertical in Mold**

After the placement of the vertical plates, the HMA mold assembly was picked up and placed on the compaction platform in the Hamburg compactor. The compaction platform is equipped with a manual hydraulic lift that lifts the mold and sample in contact with the roller. The operator can control the pressure of the lift therefore controlling the pressure exerted by the roller on the sample. The first few passes of the roller were used to seat the plates so that they were even (Figure 17).

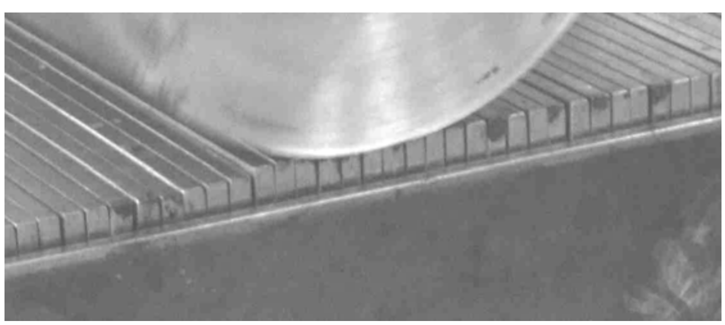

**Figure 17.  Plates Seated with Light Pressure from Roller**

After the plates were seated, they were rolled while maintaining a 1000 to 1500 psi hydraulic pressure in the rams lifting the platform with the compaction mold. Rolling continued until the tops of the plates were level with the top of the mold (Figure 18).

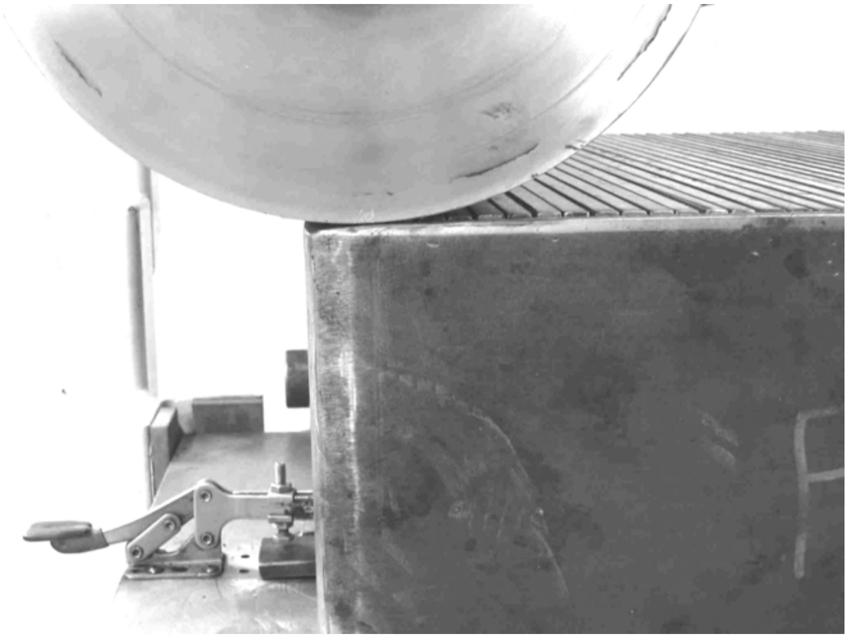

**Figure 18. Plates Rolled Down Flush with Top of Mold**

When the top of the plates were even with the top of the mold, the calculated volumetric properties met the design requirements. The compaction plates were then removed from the top of the slab. The surface of the slab in contact with the bottom of the mold during compaction was used as the test surface when obtaining texture and friction data. The top of the slab adjacent to the steel plates was not tested since it was believed to be slightly uneven and therefore would not simulate field samples. The mold and HMA slab were allowed to cool before removing the sides of the mold. While cooling, the separation paper was removed from the slab. Cooling of the slab in the mold was critical because the weight of the slab made it impossible to move when it was still hot without damaging the sample.

In conclusion, the procedure and equipment used with the walk behind vibratory roller compaction process needs some modification in both the equipment and procedure if it to be used to produce acceptable HMA slabs. The quality and smoothness of the slabs could not be controlled with the equipment and procedures used in this investigation. The distance the HMA was transported from mixing to compaction site and the placing and spreading of the mix in the mold took too long and allowed time for mix cooling. The spreading and leveling procedures allowed excessive segregation to occur in the HMA. The walk behind vibratory compactor needed to be wide enough to span the width of the mold to control the smoothness and prevent shoving the mix around in the mold.

The modified Hamburg compaction was selected as the method for making HMA slabs for this investigation. This method allowed better control on temperature loss in the mix. By quartering the mix and placing the HMA in the mold in quarters, segregation was minimized. Using the vertical plates with the Hamburg device allowed compaction with kneading action without moving the mix in the mold. Visual observations indicated that the production of the HMA slab with the modified Hamburg compaction process was much improved over the walk behind vibratory roller method.

## HMA Lab Polishing Equipment

The lab HMA polisher was designed using the following goals:

a. Test aggregates propensity to polish in the conditions in which the aggregate is being used. If the intended use is in an Open Graded Friction Coarse (OGFC), the polishing propensity will be tested using the aggregate in an OGFC. If the aggregate is to be used in a coarse graded Superpave designed mix, the aggregate's propensity to polish will be tested in a coarse graded Superpave mix. This will be addressed by making HMA slabs with different HMA mixes to be used in the polishing test.
b. The texture and friction of the polished surface should be evaluated before and after polishing using the CT Meter and the DF Tester.
c. It would be beneficial to have the polishing done by rolling wheels similar to polishing by vehicular wheels.
d. This device should be able to polish aggregate in an HMA in the field as well as in the laboratory.
e. Automatic turn off when polishing is complete.
f. Be capable of varying the normal load and speed of polisher.
g. Minimize the cost of the equipment to make it affordable as laboratory equipment.

### *Fabrication of Aggregate Polishing Test Machine*

The CT meter and DF tester evaluates the texture and friction within the outer portion of an 11-3/16 inch diameter circle. Therefore, as a minimum, the polishing device has to polish this area.

The polishing device was designed to use 8 X 3 inch caster wheels attached to a turntable so that the wheels tracked in an 11-3/16 inches diameter circle. The friction of the caster wheels on the surface of the HMA slab polishes the aggregate in the HMA slab similar to the way the vehicular tires polish the aggregate in an HMA pavement surface on a highway.  In order to mount the casters and wheels in a circle to track the desired diameter, space restrictions allowed three wheels to be mounted (Figure 19).

The casters were equipped with ball bearings that allowed the wheels to line up with the 11-3/16 inch diameter circular path (Figure 19). Circular iron plates were constructed to be placed on the turntable to change the weight on the three wheels thus changing the normal load on the three wheels (Figure 19). A square tube-like shaft was used to connect the motor shaft and penned with a slotted hole for movement up and down (Figure 20). The wheels and turntable were free to move up and down so that the weight on the wheels could be varied by adding or subtracting circular iron plates.

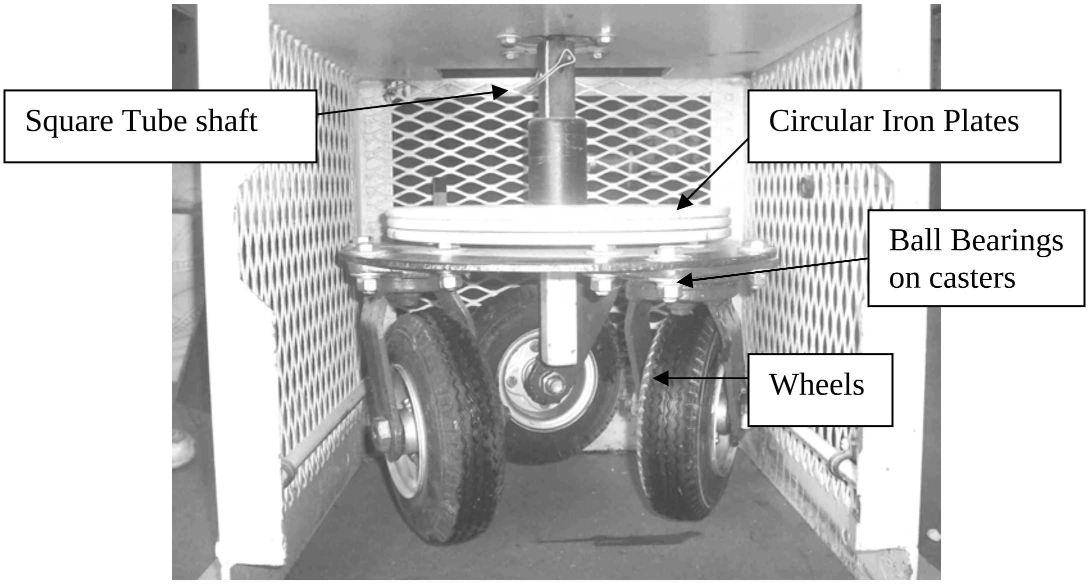


**Figure 19. Abrasion Wheel Assembly**

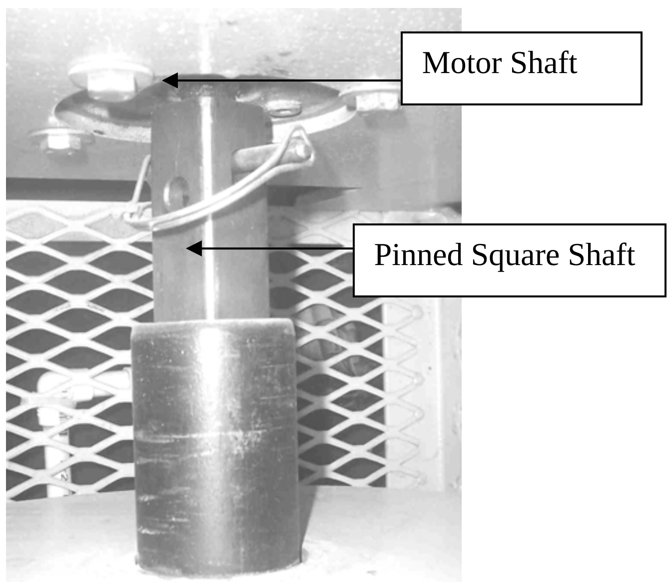


**Figure 20. Square Shaft Attached to Motor Shaft**

A square shaft that was attached to the circular motor shaft was inserted within a square shaft mounted to the turntable (Figure 21).

The square shaft transferred the torque from the motor to turn the turntable while allowing the shaft to freely move up and down during test. This would allow weight added to the turntable to be transferred to the wheels.

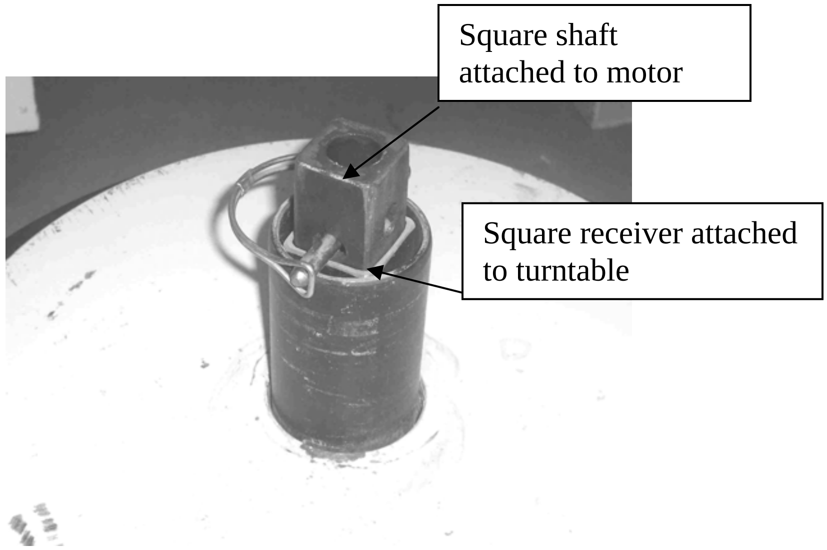


**Figure 21. Square Shaft Fitting Through Square Shaft Attached to Turntable**

The motor used to turn the wheel was an electric ½ horse-power motor requiring 110 volts (Figure 22). The motor drove a gear box that allowed better torque at low speeds. The motor was controlled by a Baldor motor speed controller that allowed the input of variable speed control (Figure 22). An Omega digital counter with a laser light pick-up was used to count the revolutions of the turntable automatically (Figure 22). The Omega counter was programmed to input the desired number of revolutions and when that number of revolutions was obtained the Omega counter turned off the power to the motor.

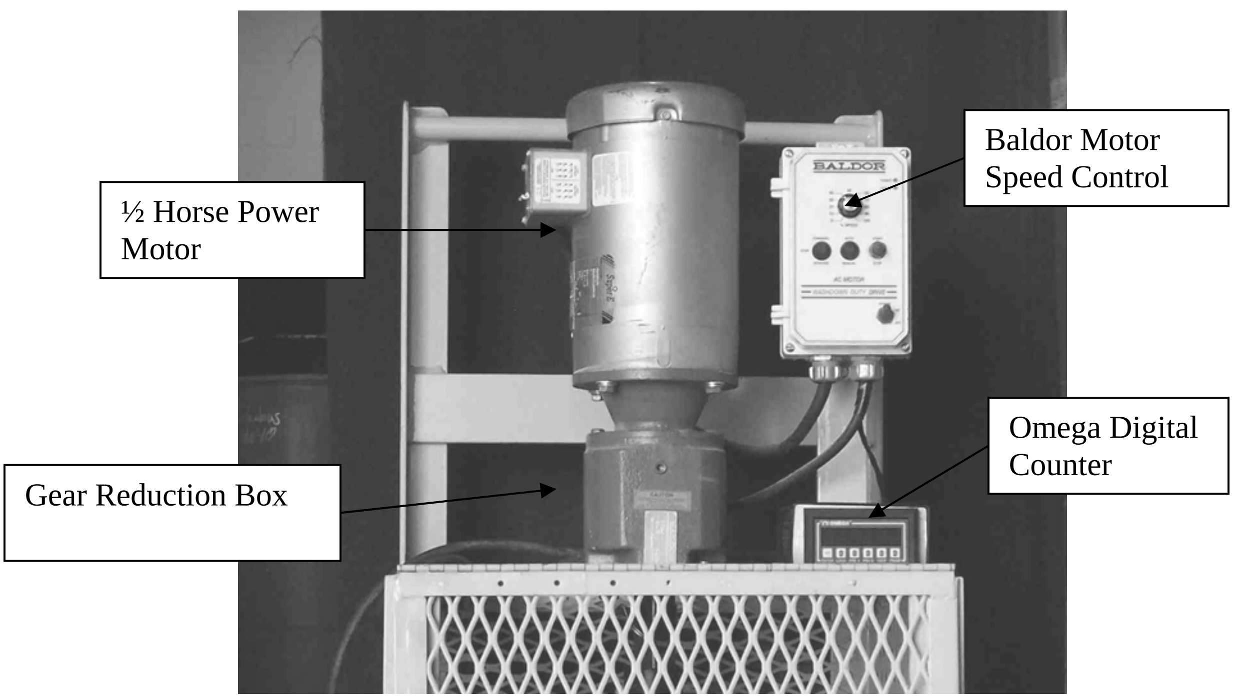


**Figure 22. Motor and Controls on Polisher**

A water spray system was added in order to spray water on the surface being polished. Water was needed in order to wash away abraded particles to allow polishing of the aggregates and also to simulate wet conditions. The water was sprayed on the surface using ¼ inch PVC pipe connected to a water supply. The PVC pipe was attached to the frame on three sides (Figure 23). Small holes were drilled into the PVC pipe that directed application of water onto the surface of the slab (Figure 23).

**Figure 23. Water Spray System**

The pressure at the water source was adjusted to control the amount of water being sprayed on the surface. An electric cutoff valve was added between the source and the spray. The electric cutoff was connected to the Omega counter so that when the desired revolutions were obtained the Omega counter would cut off both the electric motor which powered the wheels and the water to the spray system. The frame to support the systems was covered with mesh for safety (Figure 24).

**Figure 24. Protective Wire Mesh**

Rollers were installed on the rear of the frame to allow ease in moving the polisher. A top hinged door was placed on the front of the machine to allow a 20 by 20 inch slab to be inserted by rolling the polisher over a slab to be tested (Figure 25).

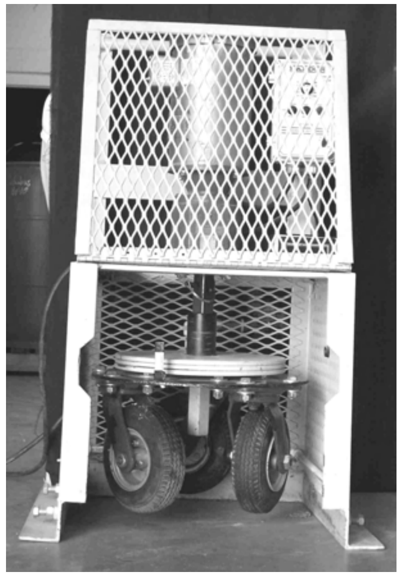

**Figure 25. Slab Placed in Slotted Area at Bottom of Polishing Machine**

*Dry and Wet Polishing Testing*

The initial testing with the polishing machine was first attempted on a dry HMA surface using three rubber pneumatic tires and then using three Bronco 08300-UV wheels. Initial observations on the rubber pneumatic tires showed excessive tire wear. It is believed that the wheel heated up to a point where the rubber was softened and balled up on the surface being polished. The balled up rubber on the surface caused the wheels to lose contact with the HMA surface thus stopping the polishing action. Therefore the use of the rubber pneumatic wheels on a dry surface was discontinued.

The Bronco wheels (Gray) were tried on the dry surface. The Bronco wheels are hard rubber (75-80 Durometer) solid wheels which were much more abrasive resistant. During the operation of the polisher using the bronco wheels, a fine dust material was abraded from the surface of the wheels and deposited and ground into the surface of the HMA being polished. Efforts were unsuccessful to air blow and /or brush these particles off the surface. It is believed that the presence of these particles affected the polishing action of the wheels on the surface of the HMA and therefore would not give realistic results. Therefore dry testing was discontinued.

A water spray system described previously was added to remove the abraded material on the surface and to simulate minimum friction under wet surface conditions. The water spray system was successful. Using the polishing device with the water spray system, HMA slabs were polished using 5 different sets of wheels. The five wheel types used are shown in Table 1.

**Table 1. Experimental Set up**

| Wheel Number | Wheel Material Description | Wheel | | Catalog # Wheel with Bearings | Capacity | Approx. Weight of Wheels | Normal Load |
|---|---|---|---|---|---|---|---|
| | | Dia | Tread Width | | | | |
| | | IN. | IN. | | LBS. | LBS. | LBS. |
| 1 | Pneumatic Wheel | 8 | 2.8 | 08300-UW | 300 | 4 1/4 | 105 |
| 2 | Payductile Iron Wheel, Steel | 8 | 3.0 | 08300-UD | 5000 | 20 | 105 |
| 3 | Miratek Polyurethane 95 Shore, Red | 8 | 3.0 | 08300-UT | 2250 | 5 | 105 |
| 4 | Bronco mold-on Wheel, Gray | 8 | 3.0 | 08300-UV | 840 | 7 1/2 | 105 |
| 5 | Phenolic Resin Wheel, Black | 8 | 3.0 | 800 | 2500 | 5 | 105 |

Five sets of three wheels were mounted on the polish device and evaluated for their characteristics of polishing the surface of an HMA. New slabs constructed to the same specifications were used with each set of wheels. The slabs were polished using cycle periods of 5, 15, 35, 75, and 95 thousand cycles. The normal load used during all tests in this phase was 105 pounds. The tire pressure for the pneumatic tires was maintained at 50 psi. This is lower than typical truck tires but higher than automobile tires and is probably a good average number for all traffic that would be expected to polish a roadway (pressure could not be controlled in the solid tires). At the end of each cycle period the polishing device was stopped and the slab was removed, dried and its surface was evaluated for texture and friction using the ASTM E 2157 Circular Track Meter (CT Meter) for texture and ASTM E 1911 Dynamic Friction Tester (DF Tester) for friction. The texture and friction measurements were made in a direction parallel and perpendicular to the direction of the roller during the compaction of the slab. The average of the parallel and perpendicular results was used to calculate International Friction Index ($F_{60}$).

It has been shown that the DF Tester value at 12.43 miles/hour (20 km/h) together with a texture measurement provides a good estimate of the friction number of IFI (8). The International Friction Index ($F_{60}$) was used to compare the polishing characteristics of the five types of wheels. The $F_{60}$ is calculated using the surface texture and the surface friction. The equation for calculating the $F_{60}$ is as follows:

$$F_{60} = 0.081 + 0.732 \times DFT_{20} \times e^{\frac{-40}{108.1MPD - 1.3}}$$

Where

| | |
|---|---|
| $F_{60}$ | International Friction Index |
| $DFT_{20}$ | Friction number obtained at 20 km/h using the DF Tester |
| MPD | Mean profile depth obtained from CT Meter |

A plot of $F_{60}$ verses number of cycles for the five sets of wheels tested are shown in Figure 26.

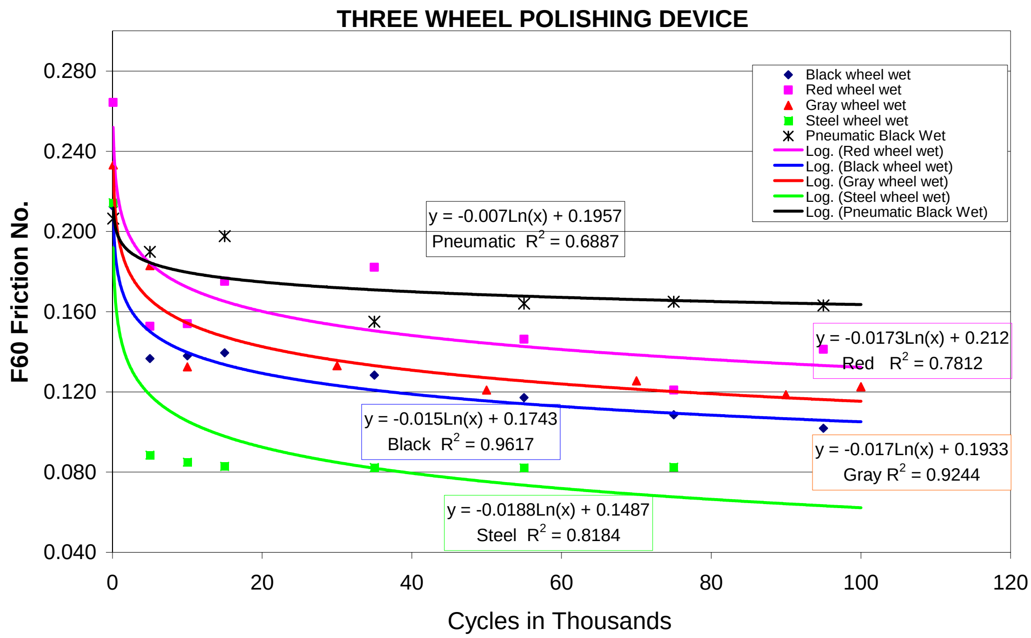


**Figure 26. IFI ($F_{60}$) Measurements Versus Cycles for Five sets of wheels**

The $F_{60}$ values plotted are the average of the values obtained parallel and perpendicular to the direction of the roller during the making of the HMA slab. The shape of the curve produced with each of the five sets of wheels are reasonable showing a high rate of friction loss between 0 and 10,000 cycles of the wheels. An explanation for the high rate of friction loss on initial cycles would be that the exposed aggregate initially had sharp edges which gave higher friction values; however, these sharp edges were worn away rapidly by the abrasive action of the wheels causing a rapid reduction of friction. It is also possible that some of the aggregate particles on the surface were reoriented such that a flatter surface was exposed reducing surface friction. The curves showed a slower rate of friction loss occurring with additional cycles for the remainder of the cycles. An explanation for the slower rate of friction loss would be that the initial removal of the sharp edges and reorienting of the surface aggregate gave a more stable surface for the abrasion and polishing action of the wheels. The Natural Log (ln) equation and R-value found for each of the five curves are also shown on Figure 26.

As shown in Table 1, five wheel types were evaluated for this study. One of the needs of this project was to determine which wheel types provided a reasonable comparison to what has been observed in the field.

The use of the steel wheel in the polishing test resulted in a severe abrasion (Figure 27) to the HMA surface and not a polishing of the surface which occurs with the other four sets of wheels and which occurs on HMA roadways.

**Figure 27. Abrasion of Surface by Steel Wheel**

As a result of this study the steel wheels are not recommended for use to simulate traffic polishing of the roadway surface and therefore no further evaluation of the steel wheels were considered. The other four set of wheels did exhibit polishing of the HMA surface and can be used for this purpose.

**NCAT Test Track Mean Profile Depth and Friction Evaluation**

Part of the testing program while applying traffic on the NCAT Test Track requires that Friction and Mean Profile Depth (MPD) measurements be taken on each section of the 1.7 mile oval track. This data was used to track and evaluate the change in surface characteristics of the track surface during application of traffic. The test track was divided into 46 sections, 200 feet long. Each section was constructed using individual HMA mixes and designs specified by the sponsor of the individual sections.

**Laboratory and Field Friction Measurements Comparison**

Three 200 feet sections from the NCAT Track were selected for comparison with the laboratory results obtained using the Three Wheel Polishing Device. Sections E 04, E 06 and S 09, which had the same aggregate type and similar aggregate gradation with the laboratory compacted slabs were selected. Mixture properties of these sections are listed in Table 2.

Friction, texture, and IFI results were compared for three sections on the test track and the three wheel polishing machine. Five sets of wheels, having different characteristics, were evaluated for polishing the slab. The results are shown in Table 3. As shown, there are differences between the track and laboratory results for the friction device (DF Tester), the texture meter (CT Meter), and the calculated IFI. No statistical analysis of the results could be performed due to the limited amount of data and the methods used in collecting the data.

**Table 2. Mixture Properties of Test Track Sections**

| Sections | E 04 | E 06 | S 09 |
|---|---|---|---|
| Aggregate Type | Granite | Granite | Granite |
| ¾” | 100 | 100 | 100 |
| ½” | 95 | 96 | 93 |
| 3/8” | 75 | 81 | 82 |
| No.4 | 42 | 52 | 53 |
| No.8 | 29 | 37 | 36 |
| No.16 | 23 | 28 | 27 |
| No.30 | 18 | 22 | 20 |
| No.50 | 13 | 15 | 14 |
| No.100 | 8 | 8 | 9 |
| No.200 | 4.6 | 4.3 | 5.7 |
| Asphalt Content | 4.7 | 5.0 | 4.7 |

Table 3 also shows that the variability of the results with the polishing device was generally less than the variability of the results measured at the track. Part of the reason for this difference in variation is that the results of the polishing device were obtained from a number of tests on one sample whereas the results in the field were obtained at a number of locations generally resulting in more field variability. The friction and texture results from the samples polished in the laboratory can be seen more as a measure of test repeatability whereas the results from the field are more a measure of mixture and test variability. The very low variability seen from samples polished in the laboratory is the result of using average numbers from one sample to get results.

It is shown in Table 3 that the pneumatic tire provides texture and friction results on polished laboratory samples closer to that observed in the field. Hence, all future work should probably be done with a pneumatic tire to provide better comparison to the field results. Work is still needed to determine optimum tire pressure, number of cycles, wheel load, etc. to get results from the laboratory procedure that compare better with field measured values.

The texture difference between the laboratory prepared and field compacted samples is likely due to the method of compaction and thus orientation of the aggregate particles in the surface. A roller was tried in the laboratory but with little success. It is believed that the laboratory roller would help to orient the aggregate particles more like those after field compaction. More work is needed to determine a laboratory procedure that better correlates with the texture in the field. This may require that additional effort be used to develop acceptable procedures with the laboratory vibratory compactor.

**Table 3. Comparison of Texture, Friction and IFI Measurements on the NCAT Test Track and With the Three Wheel Polishing Device**

| Surface Test @ end of test period* | CT Meter | | DF Tester | | IFI with E1911 |
|---|---|---|---|---|---|
| | ASTM E 2157 | STD DEV | ASTM E 1911 | STD DEV | |
| EO4 test section* | 0.632 | 0.033 | 0.442 | 0.015 | 0.259 |
| EO6 test section* | 0.693 | 0.091 | 0.422 | 0.005 | 0.260 |
| S09 test section* | 0.526 | 0.117 | 0.479 | 0.007 | 0.251 |
| PNEUMATIC wheel test slab** | 0.395 | 0.061 | 0.309 | 0.003 | 0.163 |
| STEEL WHEEL test slab** | 0.110 | 0.000 | 0.058 | 0.012 | 0.083 |
| RED WHEEL test slab** | 0.312 | 0.010 | 0.274 | 0.006 | 0.141 |
| GRAY WHEEL test slab** | 0.281 | 0.010 | 0.209 | 0.011 | 0.123 |
| BLACK WHEEL test slab** | 0.200 | 0.020 | 0.129 | 0.003 | 0.102 |

*Track section results are at 8 million axle passes
** slab surfaces results are at 95,000 cycles of the three wheel Polishing device

## SUMMARY

The primary objective of this project was to look at the potential of developing a polishing test in the laboratory that would allow for measurement of the effect of polishing on the texture and friction of HMA samples. Based on this limited study a device was developed that does show potential for polishing laboratory samples but additional work is needed to make the method more similar to that observed in the field.

A summary of the findings of this study are provided below:

a. A three wheel polishing device was developed to allow for polishing of laboratory prepared slabs and testing for texture and friction.
b. The polisher is equipped with automatic cut off that can be programmed to stop the equipment at any required number of cycles.
c. The normal load and speed of the polisher can be adjusted.

d. The cost of the polisher should not exceed $10,000.
e. The results with the pneumatic tires appeared to simulate the results seen in the field better than the solid tires evaluated.
f. Procedures and equipment were developed to construct an HMA slab in the laboratory that simulated field samples and that was compatible with the three wheel polishing machine.
g. The CT meter and the DF tester were shown to be capable of being used to measure the texture and friction of the polished surface on the laboratory manufactured HMA slab.
h. Results indicate the lab HMA polisher produces curves with a similar shape to those plotted using results from the Test Track indicating the potential for this device to be used to predict texture and friction of laboratory compacted samples.
i. The polisher has the potential to be used on field compacted mixture if needed.

## RECOMMENDATIONS

Based on this limited study the following recommendations are warranted:

1. Further development of the polisher is needed to determine the optimum load and speed of the polishing tires.
2. Laboratory samples using 2003 and 2006 NCAT track mixes should be tested and compared with results from those mixes during trafficking on the track. Investigate differences in friction and surface texture between laboratory prepared and field compacted samples.
3. Investigate instrumentation to the shaft of the Three Wheel Polishing device to determine if the change in torque on the shaft can be related to change of friction during polishing.

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