Evaluating and Improving Asphalt Pavement in the City of Pittsburgh

Phase I: A review and comparative study of asphalt mix, manufacturing and paving process

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# Table of Contents

Executive Summary .......................................................................................................................... 4

Report Findings............................................................................................................................... 8

  Mix Design Used in Pittsburgh, Maryland, and Virginia.............................................................. 8

    o Pittsburgh .............................................................................................................................. 8
    o Maryland ............................................................................................................................. 9
    o Virginia ............................................................................................................................... 10

  Effects of different types of mixture ......................................................................................... 10

Plant Manufacturing Process........................................................................................................ 11

  o Pittsburgh .............................................................................................................................. 12

Aggregate sources .......................................................................................................................... 12

  o Coarse Aggregate .................................................................................................................. 12
  o Fine Aggregate ...................................................................................................................... 13
  o Both Fine and Coarse Aggregate ......................................................................................... 13
  o The effects of maximum aggregate size to the pavement performance .................................. 13
  o Aggregate Selection Process in Pittsburgh/Pennsylvania ..................................................... 14

Pittsburgh ......................................................................................................................................... 14

Asphalt/Crude Sources .................................................................................................................... 14

  o Behavior of Asphalt Binder .................................................................................................. 14
  o Age Hardening of Asphalt Binder ......................................................................................... 15
  o Asphalt Binder and Pavement Performance ........................................................................ 15
  o Asphalt Binder/Aggregates and Different Types of Distress ................................................ 15
  o Asphalt Binder Selection Process ......................................................................................... 15
  o Effects of Different PG graded asphalt binder to the pavement performance .................... 16

Pittsburgh ......................................................................................................................................... 16

RAP and its effects on pavement performance .............................................................................. 16

  o Effects of RAP to Pavement Performance ........................................................................... 17
  o Effects of RAP on overlay to long term performance of the pavement .................................. 17
  o Effects of RAP to the pavement performance compared to virgin materials ....................... 18

Pittsburgh ......................................................................................................................................... 18

Paving Processes ............................................................................................................................ 18

  o Pittsburgh ................................................................................................................................ 20

Effects of base layer materials, drainage system, and high traffic volumes to the pavement performance ................................................................................................................................. 21

  o Pittsburgh ................................................................................................................................ 21

Effects of weather conditions, salting, truck plowing, tree sap, and other factors to the pavement performance ................................................................................................................................. 22

Recommendations ........................................................................................................................ 23
Executive Summary

Each year, the City of Pittsburgh resurfaces 50-90 miles of urban road, and the roads deteriorate over the years, adding an additional cost to both the City and residents. The ultimate goal of this research project is to review the state-of-the-art asphalt pavement development, compare the mix, manufacturing and paving process of asphalt pavement being used in Pittsburgh with neighboring states, and make future recommendations on the improvement of the durability of asphalt pavement for the City. This first phase of this research is to conduct thorough literature review of what factors attribute to the asphalt pavement to what degree, particularly in Pittsburgh, and compare the asphalt pavement process among several states in the northeast.

The City of Pittsburgh is currently using the Superior Performing Asphalt Pavement System (Superpave) for the road pavement mixture design consideration. Hot Mix Asphalt (HMA) mixture is the pavement mixture type used in Pittsburgh. Stone, sand, or gravel are combined with asphalt cement binder to create HMA mixture. Pittsburgh is currently using only the Dense Graded Aggregates for Coarse - Dense Graded HMA. The nominal maximum aggregate size of the mixtures used in Pittsburgh are 9.5mm and 19.0mm. Different Asphalt Binders are differentiated using the Performance Grading (PG) system. Currently, PG64-22 Asphalt Binder and PG76-22 Asphalt Binder are used as Surface (wearing) mix while only PG64-22 Asphalt Binder used as Intermediate (Binder) mix in Pittsburgh. While PG 76-22 asphalt binder would be used on wearing layer mixtures of primary streets, PG 64-22 asphalt binder would be used on binder layer mixtures of primary streets. The PG 64-22 asphalt binder would be used on wearing layer mixtures of secondary streets. Comparing to Maryland and Virginia, all pavement mixtures used in Pittsburgh are one-size-fits-all, categorized into only two types, for primary roads and secondary roads, respectively. Maryland and Virginia uses Coarse - Dense Graded HMA, Gap Graded HMA and some specialty HMA. The nominal maximum aggregate size of the mixtures used in those states varies from 4.75mm, 9.5mm, 12.5mm, 19.0mm, 25.0mm and 37.5mm. Each type of HMA are specifically designed for pavements considering design service life, traffic volumes, traffic speeds, vehicle composition, and equivalent single axle load (ESALs). Generally, Stone Matrix Asphalt (SMA) mixes used in both states are Gap Graded HMA mixture that provides high deformation (like rutting and tire wear) resistance and the durability of the pavements for primary roads with heavy traffic, especially heavy duty trucks. This is not used in Pittsburgh. In addition, asphalt binders and aggregates used in Pittsburgh follow standard HMA design. In cutting-edge research, their choices are dependent on weather, traffic, structural design, and the type of the base layer under the pavement.

In Pittsburgh, Lindy Paving is the contractor responsible for asphalt mix manufacture. At the Lindy Paving’s plant, the stockpiles of aggregates are surrounded by the concrete walls to prevent the contamination from different size aggregates. The loaders push the aggregate up as high as possible. The front-end loaders approach to specific aggregate stockpiles, load the aggregates and unload to the appropriate bin. The conveyor belt below the cold feed bins move the aggregates to the plant. The onsite control room adjusts the number of aggregates based on the job mix composition with the computerized system.

All the Lindy Paving’s plants are counterflow drum mix plant. Therefore, the aggregates are added to the drum at the opposite end from the burner, and the direction of the aggregate flow and the exhaust gases are opposite. Lindy Paving’s plants use baghouse as the emission control system to reduce the environmental impacts by filtering out the dust particles from the exhaust gases. The collected dust particles are returned to the HMA mix.

For all mixtures (both wearing mixture and binder mixture), the allowable RAP content on the mixture in Pittsburgh is 15%. Other states, such as Maryland and Virginia, generally uses more RAP portions than
15%. To process RAP to be used on the asphalt mix, Lindy Paving use “In-Line Processing” method. The in-line Processing method is to screen RAP particles before entering crushers. After RAP particles are crushed into desired screen size, RAP particles are screen once again through recirculation circuits. The rotation of the drum mixes the asphalt binder, dried aggregates, and the processed RAP to make asphalt mix. The end products of the asphalt mixes are sent to the silos from the drum. The asphalt mixes are stored and heated at the storage silos. The dump trucks get the asphalt mixes beneath the silos.

The RAP content in the mixture affects the pavement performance as the properties of the mixture changes as old asphalt binder from RAP interacts with raw asphalt binder. When the mixtures contain more RAP contents, the hardness of the mixture increases as the viscosity and softening point increase and as the penetration grade decreases. The viscosity of the mixture hugely increased when the mixture contains more than 20% of RAP. Also, the temperature susceptibility of the mixture increases as the mixture contains more RAP. As the mixture contains RAP, the hardness and the elastic behavior of the mixture is increased. The mixture with more than 20% of RAP would experience significant change rheological properties. The increase in RAP content of the mixture would make the asphalt binder to be elastic on the broader temperature range. For the excellent performance of the mixture with RAP, the viscosity of the mixture must be reduced by the increase in temperature of the mixture during production process and operation process.

Folino Construction does the paving operation for the pavement in Pittsburgh. Currently, Folino Construction uses truck types of flow boy and dump trucks. When the surface preparation operation is conducted for new project construction and for overlay, the pavement would be milled at first. Then the milled pavement would be vacuum cleaned and swept. Then, the tack coats would be applied to the milled and cleaned pavement. When the base of the pavement is dirt or mud that has no solid supports, the base layer of the flex area is replaced with aggregates if the soft base flexes during the transportation process. In order to check the uniformity of the surface temperature, the Raytek Gun is used during the placement process.

Folino Construction uses a slat conveyor as the paver for the placement process. For the construction of the transverse joint, Folino Construction uses the nuclear density gauge to determine the density of the pavement. In order to compact the confined longitudinal joint, Folino Construction uses the method of rolling from the hot side with 6 inch a pinch. The joint compaction specification in Pittsburgh is to have 92% minimum compaction level and density of longitudinal joint. Folino Construction makes sure that the targeted percentage of air void level after the compaction by the roller is 8%. Folino Construction uses Oscillating Vibratory Roller for the compaction process. Folino Construction uses the test strips for the rolling pattern on the pavement.

**Recommendations:**

The one-size-fits-all design of HMA in Pittsburgh is likely to overspend materials and labors on secondary roads with mild or little traffic volumes. Experimental design and field observations would help better determine the most cost effective HMA (mixture types, asphalt binders, aggregates and RAP compositions) for Pittsburgh roads, when taking into account design service life, traffic volumes, traffic speeds, vehicle compositions (buses and heavy-duty trucks), thickness of the pavement, and equivalent single axle load (ESALs) on roads. Thin Hot Mix Asphalt Overlay (THMACO) could be used to preserve the pavement condition. Also, Pittsburgh can use Open Graded Drainage Layer (OGDL) to provide the pavement drainage system.

Since the resistance of rutting and cracking react differently as the asphalt binder content changes, it is crucial for Pittsburgh to study the percentage of rutting and cracking occurring on the pavement to make changes to the asphalt binder percentage in the mixture. Also, the effects of asphalt binder on several
other distress must be studied to find the effects of asphalt binder to the pavement performance. When selecting the PG of the asphalt binder, Pittsburgh can consider choosing the asphalt binder with higher 7-day average maximum pavement temperature and lower 1-day minimum pavement temperature. However, the scientific research on the effects of asphalt binder on different distress like moisture damage must be conducted.

Since the moisture content of the aggregates leads to the massive impact on pavement performance, controlling and managing the moisture content of the aggregates stockpile is essential. Currently, the moisture content of the aggregates stockpile in Pittsburgh is controlled by making the steep slope. Pittsburgh may consider covering the aggregates stockpile to manage the moisture contents of the aggregate stockpile.

In order to make changes to the current paving practice used in Pittsburgh, the reports studying the effects of different joint geometries (like the natural response of material geometry, cut joint geometry, and wedge or taper joint geometry) to the pavement performance must be conducted. Also, the effects of different surface preparation techniques, like the use of chip seal and slurry seal, the use of the patch, and the use of milling and tack coats, to the pavement performance must be studied.

Currently, there is a lack of reports on the influences of tree saps and snow plowing on the pavement performance. Also, it is crucial to specifically research the pavement performance under Pittsburgh weather condition although there are studies on the impacts of climatic condition on the pavement performance. Also, there should be separate research on the effects of several climatic factors on the pavement condition and its performance.

The type of base layer underneath the pavement layers is critical to pavement performance. The data is mostly missing in Pittsburgh. Most of the City’s roads are likely built upon mud and dusts, rather than rocks. This can substantially affect the HMA design that would work best for Pittsburgh. Data collection and respective experiments for each base layer type would be highly recommended.

Part of the objectives of the research was to compare the pavement practices used in cities of Maryland and cities of Virginia with the current practices used in Pittsburgh. Except the mix design, other information cannot be collected as there was no response from the representative or the document cannot be released to the public. Therefore, in the near future, Pittsburgh could contact cities in Maryland and Virginia for the data and information on plant manufacturing process, aggregate sources, asphalt/crude sources, recycling process, paving process, base layer materials, and climatic condition to conduct the comparative analysis in the future.

In addition to scientific studies and experiments of pavement design, manufacturing and paving process, it is also recommended to adopt a data-drive approach to understand the underlying mechanism of pavement degradation with massive data collected over the last decade. Those data include, but are not limited to, the paving time and process of pavement, time, location and outcomes of pavement inspection and retrofit, weather conditions, traffic conditions, drainage design, bus operation, roadway design, roadways surface conditions, and any other factors that potentially affect pavement deterioration and in-service time. The data-driven research, if successful, enables accurate models of pavement deterioration over specific location and time, as well as for short-term and long-term prediction of pavement quality, allowing decision making of pavement design, paving, retrofit projects and capital planning. It may be more cost-effective than traditional physical experiments of pavement materials.
Report Findings

Each year, the City of Pittsburgh resurfaces 50-90 miles of urban road, and the roads deteriorate over the years, adding an additional cost to both the City and residents. The ultimate goal of this research project is to review the state-of-the-art asphalt pavement development, compare the mix, manufacturing and paving process of asphalt pavement being used in Pittsburgh with neighboring states, and make future recommendations on the improvement of the durability of asphalt pavement for the City. This first phase of this research is to conduct thorough literature review of what factors attribute to the asphalt pavement to what degree particularly in Pittsburgh, and compare the asphalt pavement process among several states in the northeast.

Mix Design Used in Pittsburgh, Maryland, and Virginia

Pittsburgh
The City of Pittsburgh is currently using the Superior Performing Asphalt Pavement System (Superpave) for the road pavement mixture design consideration. Hot Mix Asphalt (HMA) mixture is the pavement mixture type used in Pittsburgh. Stone, sand, or gravel are combined with asphalt cement binder to create HMA mixture. Pittsburgh is currently using just the HMA Dense Graded Aggregates with coarse graded aggregates among several types like Gap Graded mixes, Open Graded Friction mixes, and Fine- and Coarse - Dense Graded Mixes. The nominal maximum aggregate size of the mixtures used in Pittsburgh are 9.5mm and 19.0mm.

Different Asphalt Binders are distinguished using the Performance Grading (PG) system. Currently, PG64-22 Asphalt Binder and PG76-22 Asphalt Binder are used as Surface (wearing) mix while only PG64-22 Asphalt Binder used as Intermediate (Binder) mix in Pittsburgh. While PG 76-22 asphalt binder would be used on wearing layer mixtures of primary streets, PG 64-22 asphalt binder would be used on binder layer mixtures of primary streets. The PG 64-22 asphalt binder would be use on wearing layer mixtures of secondary streets.

For all pavement mixtures used in Pittsburgh, equivalent single axle load (ESALs) range of 3 to <30 million is used so that all roads in Pittsburgh are expecting to have about 400 to 3,900 trucks per day. The estimated Skid Resistance Level on all roads in Pittsburgh with current mixtures is E level estimating that One-way Average Daily Traffic (ADT) is above 10,000 passenger car units (PCU) and Two-way Average Daily Traffic is above 20,000 passenger car units (PCU). For all mixtures, the allowable amount of Reclaimed Asphalt (RAP) is 15%.

9.5mm wearing mixture with PG 64-22 Asphalt binder used in Pittsburgh is composed of Aggregate Fine 207 B3, Aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 64-22. The content of Aggregate Fine 207 B3, aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 64-22 in the mixture is 34.1%, 46.3%, 0.25%, 15%, and 4.6% respectively. 5.5% should be the total asphalt content percentage in the mixture.

9.5mm wearing mixture with PG 76-22 Asphalt binder used in Pittsburgh is composed of Aggregate Fine 207 B3, Aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 76-22. The content of Aggregate Fine 207 B3, aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 76-22 in the mixture is 34.1%, 46.3%, 0.25%, 15%, and 4.6% respectively. 5.5% should be the total asphalt content percentage in the mixture.
19.0 mm binder mixture with PG 64-22 Asphalt binder used in Pittsburgh is composed of Aggregate Fine 207 B3, aggregate 203 A67, Aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 64-22. The content of Aggregate Fine 207 B3, aggregate 203 A67, aggregate 203 A8, of ASTRIP (Bituminous Mixture Additive), RAP, and Asphalt Cement PG 64-22 in the mixture is 22.1%, 41.3%, 18.1%, 0.25%, 15%, and 3.5% respectively. 4.4% should be the total asphalt content percentage in the mixture.

The initial number of gyration, the number of gyration during the service, and the maximum allowable number of gyration are same for all mixtures used in Pittsburgh. The initial number of gyration, number of gyration during the service, and the maximum allowable number of gyration are 8,100, and 160 respectively.

Allowable Voids in Mineral Aggregate (VMA) percentage for 9.5mm wearing mixture with PG 64-22 Asphalt binder is 16%, allowable VMA percentage for 9.5mm wearing mixture with PG 76-22 Asphalt binder is 16.3%, and Allowable VMA percentage for 19.0mm binder mixture with PG 64-22 Asphalt binder is 13.8%.

Allowable Voids Filled with Asphalt (VFA) percentage for 9.5mm wearing mixture with PG 64-22 Asphalt binder is 77%, allowable VFA percentage for 9.5mm wearing mixture with PG 76-22 Asphalt binder is 75%, and Allowable VFA percentage for 19.0mm binder mixture with PG 64-22 Asphalt binder is 71%.

**Maryland**

The Asphalt Pavement mixture design criteria used in Maryland is also Superpave. Both Dense-Graded HMA mix and Gap-Graded HMA mix are used in Maryland. Most of the asphalt binder used in Maryland has a performance grade of PG64S-22 and PG64E-22.

For the surface layer, Dense-Graded HMA and PG 64S-22 asphalt binder with the nominal maximum aggregate size of 4.75mm, 9.5mm, 12.5mm, or 19.0mm are used. Gap-Graded HMA and PG64E-22 asphalt binder with the nominal maximum aggregate size of 9.5mm or 19.0mm are also used for the surface layer. For Base Layer, only the Dense-Graded HMA and PG 64S-22 asphalt binder with the nominal maximum aggregate size of 19.0mm, 25.0mm, or 37.5mm are used.

In Maryland, traffic speeds of the roads, ESALs, and the records on the occurrence of the rutting on the surface layers are considered to choose PG of asphalt binder to use on the surface layer. Traffic level of the roads would determine the aggregate consensus properties like the allowable number of gyration, angularity, qualities of the aggregate and the amount of asphalt liquid. In Maryland, HMA mixture with a nominal maximum aggregate size of 4.75 mm would be used only on the road with traffic level 1 or 2. The Gap-Graded HMA mixture would only be paved on roads with traffic level 5.

There are some unique mixes used for the particular case in Maryland. It would be useful to use Asphalt Rubber Gap Graded mix when the mixtures require more than 5000 tons. HiMA(Highly Modified Asphalt) would be used with asphalt binder PG76E-28 that has SBS polymer content of 7.5% on roads that have the issue of workability and pavement difficulties. High Dynamix Friction HMA would be used
Virginia
Like Maryland and Pittsburgh, Superpave is used in Virginia for the asphalt mixture design criteria. Dense Graded HMA mix, Gap-Graded HMA mixes and Specialty Mixes like Thin Hot Mix Asphalt Overlay (THMACO) and Open Graded Drainage Layer (OGDL) are asphalt mixtures that are paved on the Base layer, Intermediate (binder) layer, and the surface layer of the roads in Virginia.

The asphalt binders used on the Dense-Graded HMA mix are designated with letters based on contracts, specification, and special provision. Asphalt binder “A” (PG 64-22) is used on roads with low to medium traffic loads. Asphalt binder “D” (PG 70-22) is used on roads with medium to high traffic loads. Asphalt binder “E” (PG 76-22) is used on roads with high to extremely high traffic loads. Asphalt binder “(S)” is PG 64-22 with stabilizing additive that is used on roads with extremely high traffic load and has no reflective cracking resistance.

Gap Graded mix used in Virginia is SMA or Stone Matrix Asphalt. SMA would only be used on the roads with heavy to extreme heavy traffic volumes. The asphalt binders used with Gap Graded mix are PG 70-22, PG 76-22, and PG70-28.

For wearing layer, both Dense-Graded HMA mix and Gap-Graded HMA mix are used in Virginia. In Virginia, both Dense-Graded HMA mix and Gap-Graded HMA mix are used as the intermediate mix. For the base layer in Virginia, only the Dense-Graded HMA mix would be used. In order to select the types of the asphalt binder and mixture types on the particular road, the expected service life is calculated by considering the pavement layers and asphalt mix.

In Virginia, the selection of Asphalt Binder on each pavement layer would depend on the service life, traffic loading situation, ESALs, and pavement type.

For some roads in Virginia with high traffic level or high traffic loads, the particular type of mixture would be used on the roads. For these roads, the asphalt binder with high stiffness is selected to resist the movement of the pavement under loads.

There are some specialty mixes for the roads to perform specialized functions. Thin Hot Mix Asphalt Overlay (THMACO) is the gap-graded hot mix asphalt mixture with fine to medium aggregate size and 0.75-inch thickness. Open Graded Drainage Layer (OGDL) has a medium aggregate size with 2 inches thickness in order to allow water to move in the layer and to provide pavement drainage system.

Effects of different types of mixture
Dense Graded Mixes have four purposes. Dense Grade Mixes, with the layer thickness, provide the structure of the pavement. Dense Graded Mixes also provide the friction between the surface of the pavement and the vehicles for the safety of the drivers. Dense Graded mixes also can be used to fill up or patched the distress occurred on the pavement to provide the leveling of the pavement.
Each type of Dense-Graded Mixes has different advantages. Fine Graded Mixture provides low permeability, excellent workability, thin lifts, good durability for roads with low traffic volumes, and smooth surface texture. Coarse Grade Mixture provides thick lifts and the increase in macrotexture of the pavement’s surface.

Stone Matrix Asphalt (SMA) mixes are gap-graded HMA mixture that provides high deformation (like rutting and tire wear) resistance and the durability of the pavements.

Open Graded Mixes have water permeability unlike SMA and Dense Graded Mixture. There are Open-Graded Friction Courses (OGFC), Porous European Mixes (PEM), and Asphalt Treat Permeable Base (ATPB). By using OGFC and PEM as the surface mixture, the pavement tends to resist the splashing and to have the smooth surface.

**Plant Manufacturing Process**

The asphalt plant is the place where the asphalt mix is created, processed, and stored before the transportation of the mix to the paving site. The plant would dry and heat up aggregates; and mix aggregates, asphalt binder, and RAP. The plant would also store and heat up the asphalt mix, and distribute the asphalt mix to dump trucks.

There are two general types of asphalt mix plants in the US. There are continuous plant/drum plant and batch plant. Continuous plant/drum plant is the most common plant type in the US. At the continuous plant/drum plant, the asphalt binder and aggregate are dried and mixed at the drum. The drum plant makes asphalt continuously and can store the asphalt mixture for several days in heated silos. The batch plant also uses the drum to dry the aggregates, but the dried aggregate and the liquid asphalt binder are mixed at mixing chamber located at the tall batch tower. The batch plant makes asphalt mixtures in batches and can send the mixtures straight to work sites.

Both bath plant and drum plant do proportioning materials; drying and heating aggregates; mixing materials; storing mix; and providing the mix. All the steps except the mixing process are the same for both types of plants. While the batch plant mixes 3- 5 tons batches of aggregates, the drum plant continuously mixes the materials. The choice of the plant type depends on the cost of the production operation. Also, the plant type is determined by the number of mix types and the amount of each mix. If many different types of the mix are required daily, the batch plant is the ideal plant type. The drum plant is the ideal plant type if the vast quantities of few mix types are needed.

Advantages of Batch plant are: 1. It produces most accurate HMA product based on job mix composition, 2. it easily incorporates RAP or RAS to the mix, 3. it provides production control and quality control on the product, 4. batch components weighted individually before mixing process, and 5. the change in job mix composition without significant effect on quality.
Advantages of drum plant are: 1. It can be Portable or Stationary plant, 2. it creates Low Dust Emissions, 3. With a high production rate, 4. easily operated and requires less maintenance, 5. It consumes less fuel, 6. it has accurate quality control, and 7. proper drying and mixing process.

**Pittsburgh**

In Pittsburgh, Lindy Paving is the contractor responsible for asphalt mix manufacture. At the Lindy Paving’s plant, the stockpiles of aggregates are surrounded by the concrete walls to prevent the contamination from different size aggregates. The loaders push the aggregate up as high as possible. The front-end loaders approach to specific aggregate stockpiles, load the aggregates and unload to the appropriate bin. The conveyor belt below the cold feed bins move the aggregates to the plant. The onsite control room adjusts the number of aggregates based on the job mix composition with the computerized system.

All the Lindy Paving’s plants are counterflow drum mix plant. Therefore, the aggregates are added to the drum at the opposite end from the burner, and the direction of the aggregate flow and the exhaust gases are opposite. Lindy Paving’s plants use baghouse as the emission control system to reduce the environmental impacts by filtering out the dust particles from the exhaust gases. The collected dust particles are returned to the HMA mix.

To process RAP to be used on the asphalt mix, Lindy Paving use “In-Line Processing” method. The in-line Processing method is to screen RAP particles before entering crushers. After RAP particles are crushed into desired screen size, RAP particles are screen once again through recirculation circuits. The rotation of the drum mixes the asphalt binder, dried aggregates, and the processed RAP to make asphalt mix. The end products of the asphalt mix are sent to the silos from the drum. The asphalt mixes are stored and heated at the storage silos. The dump trucks get the asphalt mixes beneath the silos.

**Aggregate sources**

HMA mix is mainly composed of asphalt binder, air, and aggregates. Out of three major components, aggregates are filled up the most of HMA mix (around 80-95%). Since HMA mix mostly consists of aggregates, the aggregates used in the HMA mixture have huge impacts on the pavement performance. The primary role of aggregates in HMA mix is to carry and distribute the traffic loads without any significant deformation of the pavement. The aggregates affect stability, flexibility, durability, permeability, workability, friction, fatigue cracking, and tensile strength of the HMA mix pavement. The aggregates used in the HMA mix can be separated into fine aggregate and coarse aggregate based on the size of the aggregates. The interaction between these aggregate particles affects the strength and the deformation of the pavement.

**Coarse Aggregate**

Coarse Aggregate is the large graded aggregate that is hard, sturdy, durable and uncoated particles. The properties of coarse aggregate that affect the HMA pavement performances are the gradation, surface texture, particle shape, absorption and specific gravity, affinity for asphalt, abrasion resistance, and soundness. The surface texture and affinity for asphalt of coarse aggregates influence the asphalt and aggregate bond. The gradation and particle shapes affect the stability of the HMA mix. The ability of pavement maintaining skid resistance depends on the ability of coarse aggregates to resist the abrasion.
**Fine Aggregate**

Fine graded aggregates in the HMA mixture also impact the performance of the pavement. The rutting and fatigue cracking resistance of pavement depend on the properties of fine aggregates. Essential properties of the fine aggregates for pavement performance are amount, shape, angularity, and surface texture. The surface texture of aggregates affects the bond between asphalt and aggregate. The stability of the HMA mix depends on the gradation of aggregates, the particle shapes of aggregates, and the harmful materials.

**Both Fine and Coarse Aggregate**

Both coarse and fine aggregates affect the long-term skid resistance and performance of the pavement. The fine aggregate affects the micro texture of the pavement for the skid resistance of the HMA pavement. Coarse aggregates majorly affect the skid resistance of the HMA pavement by controlling the macrotexture of the pavement (FHWA 2017b). It is crucial for coarse aggregates to resist the wearing of the pavement to maintain the skid resistance. The aggregate with various minerals tends to maintain micro texture well. The softness of the aggregates influences the ability of the pavement to maintain macro texture over time.

The aggregate gradation affects the stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and moisture damage resistance of the pavement. The compaction and lift thickness of the pavement mix depends on the maximum size of aggregate. The angularity, flat and elongated particles and clay content of aggregates are essential for the pavement performance. The angularity of coarse and fine aggregates is essential for rutting prevention. The flat or elongated particles in the aggregates are essential for the workability and compaction of the pavement. Based on the traffic loading (the traffic level over 20 years of operation) and the depth below the surface, the standards on angularity, flat and elongated particles and clay content of aggregates are decided. Therefore, it is essential to consider the properties of aggregates for the long-term performance of the pavement.

**The effects of maximum aggregate size to the pavement performance**

The Voids in Mineral Aggregate (VMA), air voids, and asphalt content of the mixture have the relationship between the maximum aggregate sizes. As the maximum aggregate size increases, the VMA and the air voids of the mixture tend to decrease. The amount of asphalt needed for the mixture decreases as the maximum aggregate size increases. Since the maximum aggregate size affects the asphalt content, the VMA, and the air voids of the mixture, the maximum aggregate size has enormous impacts on the pavement performance. The potential and the severity of the permanent deformation on the pavement depends on the aggregate sizes.

The stability of the pavement and the tensile strength of the pavement have the positive relationship with the maximum aggregate size. The increase in the maximum aggregate size of mixture gradation would improve the creep performance, resilient modulus and tensile strength of the pavement. The pavement would experience less permanent strain when the mixture with a large maximum aggregate size is used. The amount of stresses experience at the underlying layers would also decrease as the maximum aggregate size increases. The increase in maximum aggregate size also helps pavement to resist the rutting.
Aggregate Selection Process in Pittsburgh/Pennsylvania

The codes used by the PennDOT can be divided into four categories: supplier code, materials code, materials class, and rock types. Materials code shows whether the aggregates are the coarse aggregate (203), fine aggregate (207), Antiskid (249 with following number representing types (AS1, AS2, AS3, AS4), or Rock lining (283) (PennDOT 2016). Material class shows the type of stone (A, B, C) that the coarse aggregate is. Type A aggregate has better quality than other types of aggregate. Rock type shows the composition of the aggregate. GL represents Gravel aggregate, SL represents Slag aggregate, and RL represents Rock Lining.

Pittsburgh

#8 Aggregate would be used for the HMA mixes with the nominal maximum aggregate size of 9.5mm. Aggregate 203 A67 would be used for the HMA mixes with the nominal maximum aggregate size of 19.0mm. Fine Aggregate (manufactured sand) from Hanson Aggregates BMC, Inc is used on all asphalt pavement mixtures. All the coarse aggregates are composed of stone since there is no letter assigned for rock type. For wearing mixture, 34.1% of Aggregate Fine 207 B3 and 46.3% of Aggregate 203 A8 are used. For binder mixture, 22.1% of Aggregate Fine 207 B3, 41.3% of Aggregate 203 A67 and 18.1% of Aggregate 203 A8 are used.

Asphalt/Crude Sources

Asphalt Binder is the mixture of hydrocarbons with the full range of molecular weights. Asphalt consists of carbon, hydrogen, and sulfur. There are Asphaltenes and Maltenes in the Asphalt Cement. Asphalt content of the mixture depends on the type of nonpolar solvent precipitating the asphaltenes. Within asphaltenes, there are Saturates, Naphthene Aromatics, and Polar Aromatics. Maltenes are composed of Resins and Oils. Resins provide the homogenous asphalt liquid by dissolving the asphaltene Maltenes are oily components that disperse the asphaltenes. In the asphalt binder, asphaltenes (polar molecules) are dissolved in maltenes (non-polar fluid). Asphaltenes would form weak molecular bonds when the maltenes have very little molecular interaction in the asphalt binder. The formation, the break, and the reformation of the asphaltenes bond affect the physical properties of asphalt. The polar interaction of molecules affects the asphalt’s flow behavior at high temperature. Depending on the polar functionality and molecules geometry, the arrangement of the asphalt molecules become either more ordered or less ordered at low temperature.

Behavior of Asphalt Binder

Since the asphalt binder is the viscoelastic materials, asphalt binder’s behavior during service depends on various factors like temperature, loading time, stress sensitivity or stress magnitude, and age of the asphalt binder. Depending on the loading time, the asphalt binder’s behavior changes. The strain rate of the pavement depends on the viscoelastic behavior, the temperature, and time. The load response of the asphalt binder depends on the pavement temperature. The stiffness of the asphalt binder is affected by the loading time and the temperature of the pavement. The properties like viscosity, stiffness, ductility, penetration, shear, and temperature susceptibility are affected by the rheological properties of asphalt binder, or the flow behavior of asphalt binder under force, deformation, time.
Age Hardening of Asphalt Binder

The age hardening or the change in the durability of the asphalt binder occurs due to several factors like oxidation, volatilization, physical hardening, polymerization, thixotropy, syneresis, and separation. The aging hardening of the asphalt binder can occur in a short time period or in extended time at different places. The short-term age hardening happens at the hot mix plant. The long-term age hardening occurs during the operation of the pavement.

Asphalt Binder and Pavement Performance

Asphalt binder has several roles in the pavement performance. Asphalt binder is used to coat the aggregates during the mixing process. Asphalt binder affects the stretchiness of the mixture, the durability of the mixture, the elastic recovery of the mixture, and the mixture’s ability to resist the deformation. There are some desirable characteristics of asphalt binder for the excellent pavement performance. It is desirable for asphalt binder to have excellent adhesion with aggregates and to have excellent long-term durability. The stiffness of the asphalt binder at the particular stage is significant for the pavement performance. At construction temperature or at low in-service temperature, asphalt binder with low stiffness performs better. Asphalt binder with high stiffness is desirable at high in-service temperature. Therefore, the asphalt binder having a high stiffness at the early stage and after the construction improves the pavement performance as mixture’s ability to resist the rutting increase.

Asphalt Binder/Aggregates and Different Types of Distress

Asphalt binders and aggregates are very important for the pavement’s resistance and the prevention of the distress like rutting (shoving), alligator fatigue cracking, low temperature cracking (thermal or transverse cracking), raveling, and bleeding/flushing. In order to minimize the rutting on the pavement, it is desirable for asphalt binder to have high viscosity, high stiffness, and low shear. It is desirable for asphalt binder to have low viscosity, low shear susceptibility, and high ductility to improve the pavement mixture’s ability to resist the fatigue cracking. The pavement with a low viscosity, low stiffness, and high ductility experiences less temperature cracking. Asphalt with high ductility, low-temperature susceptibility minimizes the raveling on the pavement. The aggregate surface chemistry and texture significantly determines the pavement’s ability to resist the bleeding and flushing. The asphalt binder also has some impacts on the resistance to the bleeding and flushing. The aging of the asphalt binder decreases the permanent deformation and the adhesion between asphalt and aggregates. Fatigue cracking, thermal cracking, and the raveling increase on the pavement as the asphalt ages. The pavement depth and the percentage of air voids in the pavement are significant for the aging impacts on the pavement. At the low oxidation rates, the aging of the pavement slowly occurs.

Asphalt Binder Selection Process

Different Asphalt Binders are distinguished using the Performance Grading (PG) system. PG of the Asphalt Binder is assigned based on climate, traffic, structural design, layer location, and fundamental properties. PG Grading System also considers the estimated loading speed on the pavement for the selection of the asphalt binder. Since the asphalt binder is the viscoelastic materials, the behavior of the asphalt binder is different depends on the traffic speed. In order to select the appropriate asphalt binder for the pavement, it is essential to consider the environmental condition of the place where the pavement will be placed. The average of high pavement temperature of 7 days and the lowest pavement temperature of 1 day are considered for the selection of appropriate PG of the asphalt binder for the pavement mixture.
Also, the estimated loading time on the pavement (like slow and stationary load) is also considered for the PG selection. The air temperature and the geographic area must also be considered to select the appropriate asphalt binder for the pavement performance. The mixture specimens at the mixing process, aging process, and the compaction process are considered. The temperature during the mixing process and the compacting process are determined for the best pavement performance. The volumetric properties of the asphalt binder like the number of gyration and the maximum theoretical specific gravity are considered for choosing the appropriate asphalt content in the mix. The content and the volumetric properties are determined to achieve the mixture with 4% of air voids. While requirement on number of gyration at initial stage, maximum number of gyration, VMA, and VFA must be checked, it is essential to check the designed number of gyration since it determines the air voids percentage, voids in mineral aggregates (VMA) percentage, voids filled with asphalt (VFA) percentage, and Dust to Binder Ratio of the pavement mixture.

**Effects of Different PG graded asphalt binder to the pavement performance**

Rutting, Fatigue cracking, and thermal cracking can be prevented by using the right PG of asphalt binder and aggregates. The mixture’s content of the asphalt binder affects the pavement’s susceptibility to rutting and cracking. As the mixture contains more asphalt binder, pavement’s susceptibility of rutting increases since the friction between particles decrease in the mixture. As the 7-day average maximum pavement temperature or the 1-day minimum pavement temperature change, the rutting resistance or the thermal resistance of the pavement changes respectively.

**Pittsburgh**

Currently, PG64-22 Asphalt Binder and PG76-22 Asphalt Binder are used as Surface (wearing) mix while only PG64-22 Asphalt Binder used as Intermediate (Binder) mix in Pittsburgh. The Asphalt/Crude Sources used by Lindy Paving are PG64-22 and PG 76-22 asphalt binder.

**RAP and its effects on pavement performance**

RAP, or Recycled Asphalt Pavement, is the asphalt pavement reclaimed from old roads. The use of RAP can provide economic and environmental benefits. Due to the introduction of RAP concept and the development of the recycling technologies, the demand for non-renewable resources like asphalt and aggregate can decrease. The decreased demand for asphalt and aggregate leads to the total cost associated with the mixture can decrease. The decrease in the demand for non-renewable resources also leads to the reduction in the efforts of extracting and transporting asphalt and aggregates. The fewer efforts in extraction and transportation process save the energy and reduce the emissions.

There are several methods of obtaining RAP. The most common method of obtaining RAP is through cold planning or pavement milling operation. Another method of obtaining the RAP is the full depth pavement demolition. RAP can be obtained by performing the utility cuts in a roadway, removing the isolated areas to do patching, and completely demolishing the existing pavement using a bulldozer or backhoe. The final method of obtaining RAP is from the Wasted Asphalt Plant Mix. During the Asphalt plant operation, the material wastes are created at the beginning, during the operation, and at the end. Wasted mixes are collected during the placement process.

The contamination of the RAP must be checked for the uniformity of stockpile and the pavement performance. Since RAP affects the pavement performance, the management and the process of RAP are vital. By having an excellent material management practice for the asphalt mix production operation, high quality of mix with high contents of RAP can be produced. In order to do the RAP management, it is
essential to check the availability of RAP and the amount of RAP needed during the mix production process.

Having single RAP stockpiles or multiple RAP stockpiles based on the sources is the one of the first decision that the contractors must make. Some agencies might restrict the RAP stockpile not to have additional materials after it is tested and processed. Processing and Crushing RAP is vital to keep the consistency of the RAP stockpile. When the RAP is from the milling process, it is crucial to process the millings. When the millings are from the single project, the millings have very consistent gradation, asphalt content, properties of aggregates and binder

There are several types of crushers like horizontal shaft impactor, roller or mill type breaker, HIS crusher, compression type crushers, Hammermill crushers, and milling machine. Moisture content and the temperature also affect the crushing and screening process of the RAP materials.

After RAPs are processed at the screening and crushing location, the processed RAPs are transported to the feeding location. Loaders would dig the multiple parts of the RAP stockpile and remix the loads. Then the loaders would create the stockpile near the feeders. Therefore, the materials can be remixed and improved its consistency during the transportation. The segregation of the RAP stockpile has to be prevented as it can affect the pavement performance. Moisture content in the atmosphere affect the mixture production rate and the costs associated with drying the aggregates and RAP for the mixing process. With excellent management, RAP stockpile might have better consistency in gradation than raw aggregate stockpile.

There are three different testing methods to determine the asphalt content and the aggregates’ properties. Ignition method (AASHTO T 308 or ASTMD6307) is the testing method with low testing variability and excellent accuracy. Solvent extraction method uses the solvent like Trichloroethylene to determine the aggregate properties and asphalt properties in RAP. When more RAP materials are added to the RAP stockpile through the continuous replenishment, the sampling and testing are conducted every 1000 tons.

While producing the mix with the use of RAP, several factors must be carefully considered. It is essential for the contractors to minimize the moisture content of the RAP stockpiles. The uniformity and the consistency of the RAP used in the mixtures are essential for the pavement performance. Depending on the moisture content and the variation on the RAP, the amount and the variability of raw asphalt binder added to the mixture changes.

**Effects of RAP to Pavement Performance**

When the RAP is used on the mixture, it is essential that the mix with RAP meet the same requirement as the mix without RAP. It is also vital that the performance of the mix with RAP to be same or better than the performance of the mix without RAP. When the RAP is used for the pavement mixture, the stiffness of the mixture increases. Therefore, the pavement mixture with RAP tends to experience premature cracking at intermediate and low temperature. Since the use of RAP in the mixture increases the stiffness of the mixture, the asphalt binder has to be modified. Therefore, the asphalt binder stronger at the critical temperature is used when more RAP is used in the mixture.

**Effects of RAP on overlay to long term performance of the pavement.**

The effects of RAP on the pavement performance depends on the thickness of the pavement overlay and the intensity of the pre-overlay treatment. When the overlay has the thick thickness of about 127mm with proper overlay treatment, the pavement with the mixture containing RAP has better resistance in rutting and cracking and has increased stiffness compared to the pavement with raw aggregates.
**Effects of RAP to the pavement performance compared to virgin materials.**

The RAP content in the mixture affects the pavement performance as the properties of the mixture changes as old asphalt binder from RAP interacts with raw asphalt binder. When the mixtures contain more RAP content, the hardness of the mixture increases as the viscosity and softening point increase and as the penetration grade decreases. The viscosity of the mixture hugely increased when the mixture contains more than 20% of RAP. Also, the temperature susceptibility of the mixture increases as the mixture contains more RAP. As the mixture contains RAP, the hardness and the elastic behavior of the mixture is increased. The mixture with more than 20% of RAP would experience significant change in rheological properties. The increase in RAP content of the mixture would make the asphalt binder to be elastic on the broader temperature range. For the excellent performance of the mixture with RAP, the viscosity of the mixture must be reduced by the increase in temperature of the mixture during production process and operation process.

**Pittsburgh**

The RAP is collected from millings, not from pavement demolition and plant waste. RAPs used in Pittsburgh are from multiple RAP sources collected at state’s projects. The stockpiles are created by pushing the RAPs as high as possible with Front-end Loaders while trucks unload the RAPs. The steep slope of the stockpile would lead to water drain down along the slope and prevent the moisture problems. Front-end loaders would haul the RAP stockpiles and unload at the RAPs feeder bins. Then the conveyor belt under the RAP feeder bins would move the RAPs to the crushers.

The Lindy Paving use the in-line process for the RAP. In the in-line process, the RAPs are screened before entering the crushers so that fine RAPs are separated from the large RAPs. The large RAPs are crushed into desirable screen size at the horizontal shaft impactor crusher. After RAPs pass the horizontal shaft impactor crusher, the RAPs enter in-line recirculation circuits to check the size of crushed RAPs. RAPs are dried through the counter-flow dryer before RAPs mix with HMA aggregate and asphalt binder.

For all mixtures (both wearing mixture and binder mixture), the allowable RAP content on the mixture is 15%.

Sampling on the RAP stockpile is created when the RAP stockpile is created and when the RAP is fed into the plant for the HMA mixture. Currently, Lindy Paving conducts the testing on mixes and the RAP. The testing on the RAP stockpile for measuring the asphalt content and gradation of RAP is conducted for every 500 tons of delivered RAP. RAP burn testing is conducted for every 1000 tons of RAP during the production of HMA mixture to measure the moisture content, asphalt content, and gradation of RAP. Lindy Paving use the ignition methods to test the aggregate properties and the asphalt properties of the RAP while solvent extraction method is rarely used for the verification of the test results of the ignition method.

**Paving Processes**

After the processed mixture are stored at the silos, trucks would arrive at the plant. Trucks’ mission is to transfer the mixture created at the plant to the paving site while preserving the mixture temperature, blend, and properties. The segregation can occur during the transportation. Mix segregation leads to high air voids percentages, raveling, and cracking.
When trucks arrive at the plant, the mixtures are dumped into the three parts (rear, front, and middle) of the truck’s bed from the silos to prevent the segregation of the mixtures. There are three types of trucks: end dump trucks, live bottom trucks, and belly dump trucks. Depending on the type of trucks, the mix would be dumped into the truck’s bed in a different order. For each type of trucks, the unloading process is slightly different. After the mixtures are unloaded, the bed and the tailgate of trucks are cleaned at the designated clean up area.

Some contractors use Material Transfer Vehicle (MTV). When MTV is used, the trucks dump the mixture to MTV, not to the pave. The use of MTV would prevent the segregation during the transfer, support the continuous paving operation, eliminate the potential of trucks bumping into the paver, preserve the consistent mat temperature, and improve the smoothness of the mat.

Asphalt mixture placement processes can be separated into four processes: surface preparation, lay down, joints, and compaction.

When the mixture is paved as new construction, it is essential to consider the compaction on the subgrade and base course.

Asphalt mixture is paved as overlays to fill the cracks, fatigued areas, potholes, and ruts, to fix the drainage deficiencies of the pavement, to clean the surface of the pavement, to level the course and to apply tack coat on the pavement. By overlaying the mixture to the existing pavement, the severely damaged areas and potholes are patched on both base course and HMA mixture. Ruts happened on the pavement can be milled or filled. Millings are performed for rehabilitating the pavement and for improving the surface’s performance cost-effectively.

When the tack coat is applied, the condition of the pavement determines the application rate of the tack coat. In order to keep the tack coat down on the pavement for the bond between lifts, several methods exist.

While laying down the asphalt mixture for the placement, it is vital to transfer uniform and consistent mix at a specific mixture temperature from the paver to the screed. The number and seriousness of the cracking depend on the temperature difference from the thermal streaks to the other areas on the pavement and the location of longitudinal segregation.

With lots of track drive systems, pavers would arrive at the paving site to place the mix on soft materials or layer. Tracks units are composed of push roller and truck hitches, hopper, slat conveyors, conveyors flow gates, and augers. The speed of paver and the augers do not influence the operation of slat conveyor on the paver. In order to prevent the segregation and streaks at the longitudinal centerline of the mat behind the paver, the kickback paddles are installed to push the mix under the gearbox away.

The problems can occur different locations of pavers from the early stage like stockpiling and loading operation to the late stage like laydown process. The segregation on the pavement is eliminated by having the consistent paving operation.

Screen unit of pavers consist of two points and screed arm, thickness control screws, crown control, extensions and end plates, strike off the plate, screed plate, pre-compaction system, and screed heater. The angle of attack, thickness adjustment controls, the head of the material volume, the speed of paver, and the height of lead and tail crown can affect the paving operation and the pavement performance.

There are several automatic grade control devices used during the paving process. Stringline, mobile reference, joint matching shoe, the sonic sensor, and laser are some automatic grade control devices.
Different types of joints are used during the mixture placement procedure. There are longitudinal and transverse joints. Within the longitudinal joints, there are confined and unconfined longitudinal joints. Confined longitudinal joint and unconfined longitudinal joints have different process and features. Depending on the types of the joints used, the construction and compaction processes change. There are several methods of using transverse joints like Papered Transverse Joint and Vertical Joint Face. The nuclear density gauge and the straight edge is used for the joints operation.

While rolling the joint transversely for the compaction, various factors like traffic, steep side slopes, and guard rails affect the rolling operation.

Longitudinal joints have several different joint geometries. Depending on the geometries of the joint, there are the natural response of material geometry, cut joint geometry, and wedge or taper joint geometry.

It is also vital to not scatter or push the overlapped material for the leveling of the roads and the pavement performance.

There are several compaction strategies for using the confined longitudinal joints: rolling on the hot uncompacted mat with 6in overlap, rolling from the hot side with the 6in pinch, rolling on the cool side with 6in overlap.

Several factors like compaction level and air void percentage must be considered for the compaction process during the asphalt mixture placement operation.

When the maximum density of mat percentages increases, the resistance to cracking, rutting, stripping, and raveling would increase. The durability of the mat increases as the maximum density of mat percentages increases. The flushing/bleeding resistance would increase when the maximum density of mat percentages decreases.

There are three types of self-propelled compaction equipment used to compact the mat. There are static steel wheel roller, pneumatic rubber-tired roller, and vibratory roller. The use of each roller types is different during the compaction.

Several factors affect the needed time for the compaction process. Some of the factors are materials properties, environmental condition (ambient air and base course temperature, HMA temperature, wind velocity, and solar flux), the laydown site condition, and thickness of the mat. In order to create rolling patterns from the test or control strip, there are several critical processes to be done.

It is essential to balance the production process and the construction or the paving process. It is tough to balance the production process and the paving process as there are several factors like trucks arriving together for unloading, the paver operating at various speed, and roller being re-watered. In order to balance the production and paving process with these issues, the roller tends to operate at the higher production rate.

**Pittsburgh**

Folino Construction does the paving operation for the pavement in Pittsburgh. Currently, Folino Construction uses truck types of flow boy and dump trucks. When the surface preparation operation is conducted for new project construction and for overlay, the pavement would be milled at first. Then the milled pavement would be vacuum cleaned and swept. Then, the tack coats would be applied to the milled and cleaned pavement. When the base of the pavement is dirt or mud that has no solid supports,
the base layer of the flex area is replaced with aggregates if the soft base flexes during the transportation process. In order to check the uniformity of the surface temperature, the Raytek Gun is used during the placement process.

Folino Construction uses a slat conveyor as the paver for the placement process. For the construction of the transverse joint, Folino Construction uses the nuclear density gauge to determine the density of the pavement. In order to compact the confined longitudinal joint, Folino Construction uses the method of rolling from the hot side with 6 in a pinch. The joint compaction specification in Pittsburgh is to have 92% minimum compaction level and density of longitudinal joint. Folino Construction makes sure that the targeted percentage of air void level after the compaction by the roller is 8%. Folino Construction uses Oscillating Vibratory Roller for the compaction process. Folino Construction uses the test strips for the rolling pattern on the pavement.

**Effects of base layer materials, drainage system, and high traffic volumes to the pavement performance.**

The variability in the stiffness of the aggregates in the base layers would affect the performance of the HMA pavement. When the loads are placed on the viscoelastic HMA layer, the HMA layer, aggregate base layer, and subgrade layer experience the changes. When the properties of the aggregate base layer changes, the pavement experience fatigue cracking and rutting. The base aggregate layer affects the quality and the performance of the pavement. The stiffness and deformation of resistance of the foundation layer must be right for the excellent pavement performance. Aggregate base layer supports the surface HMA layer, distributes the loads and weight applied to the pavement, and supports the drainage system of the road infrastructure.

The change in gradation, moisture content, density, and the shape of the base aggregate layer affect the nonlinear resilient modulus of the aggregate. The change in linear resilient modulus of the base aggregate affects the possibility of the fatigue cracking and rutting on the HMA pavement. The asphalt layer is significantly influenced by the variation of base aggregates’ properties. The performance of the HMA pavement is also influenced by the curvature and the moisture content of the aggregate base layer.

Tensile strain occurred on the underlying layer of pavement surface leads to bottom-up fatigue cracking. The performance of the pavement, especially the thin pavement layer, is affected by the possibility of the fatigue cracking on the pavement. The coefficient of curvature, maximum dry density (aggregate gradation), and moisture content ratio of the aggregates affect the allowable load weight on the pavement and the pavement's ability to resist the rutting. The stiffness and deformation of resistance of the foundation layer must be right for the excellent pavement performance.

Water on the pavement surface can affect the safety of the drivers and maintenance of the pavement. Excess water from rain, groundwater, or precipitation gets into the pavement through cracks, infiltration, shoulders, and ditches by gravity, capillary forces, osmotic forces, and differences in temperature or pressure. Due to the water on the pavement, the pavement would experience the moisture damage, reduction of modulus, and the decrease in strength. The quality of the drainage system of the road infrastructure systems affects the structural and functional performance of both flexible and rigid pavement.

Among several factors affecting the pavement performance, loads of the vehicles significantly affect the pavement service time since the trucks are one of the most massive vehicles on the pavement. The
number of axles on the pavement and the weight of the axles influence the severity of the damage on the pavement. As the axle weight of the trucks increases, the severity of the damage on the pavement increases almost exponentially. The effects of the axle spacing on the pavement performance depend hugely on the structure of the pavement although axle spacing impacts the wear on the pavement. The speed of the trucks is also important factors affecting the damage on the pavement. The garbage trucks also affect the deformation on the pavement and the performance of the pavement as it is one of the most massive vehicles driving on the city streets although it depends on the type of street and the number of garbage trucks on the pavement.

**Pittsburgh**

Currently, the underlying layer of the pavements in the Pittsburgh consists of cobblestone, brick, concrete, or dirt/mud. 50% of the underlying layer of the pavements in Pittsburgh consists of cobblestone, 10% of the underlying layer of the pavements in Pittsburgh consists of brick (yellow bricks and red bricks), another 10% of the underlying layer of the pavements in Pittsburgh consists of concrete, and final 30% of the underlying layer of the pavements in Pittsburgh consist of dirt/mud. The rail tracks also exist under the pavements.

Cracking can occur on the pavement where the track line exists on the underlying layer. Also, the potholes can happen at the place where the utility cuts exist. For the pavements on the slide, the pavements would move slowly along the slope of the hill. When the pavements slide, the cracking can occur on the pavements. Also, it is possible that the level of the pavement layer to be not uniform. The pavements placed on the mud or dirt can experience deformation as the base layer cannot provide the solid supports. When the garbage trucks or buses move on the pavements, the pavements, especially those placed on mud or dirt, can experience cracking and other distress.

**Effects of weather conditions, salting, truck plowing, tree sap, and other factors to the pavement performance.**

The pavement performance and its service lifetime are affected by climate and the environmental conditions like precipitation, temperature, and moisture content. The performance of the HMA pavement is affected by the external climatic factors like precipitation, temperature, humidity, freezing/thawing, and water table level. Air temperature, solar radiation, asphalt surface radiation, and speed of the wind determines the surface temperature of the pavement. Although weather condition like transpiration, condensation evaporation, and sub-limitation affect the pavement performance, the effects of these weather conditions can be neglected as their effects on pavement performance can be opposite and cancel other effects. Rutting, age hardening, and thermal cracking on pavements relate to the stiffness of the pavement and rutting performance of the pavement. Stiffness and the rutting performance depends on the pavement temperature due to viscoelastic behavior of the asphalt binder. Climatic factors like precipitation, runoff, and evapotranspiration; type of soil; and the level of water table influence the soils’ moisture percentage. Depending on the moisture content of the soil, the stiffness and the resilient modulus of unbound materials and subgrade materials change. As a result, the moisture content of the soil affects the susceptibility of pavement to the permanent distress.

Frost heave and thaw cycle affect the strength of the pavement and the severity of the distress on the pavement. The increase in annual average temperature and the seasonal variation temperature make the pavement to be more susceptible to longitudinal cracking, fatigue cracking, and rutting.
Throughout the year, the lowest average high temperature and average low temperature occur in January with the temperature of 37 Fahrenheit and 21 Fahrenheit respectively. The highest average high temperature and average low temperature occurs in July with the temperature of 83 Fahrenheit and 66 Fahrenheit respectively.

Snow on the pavement leads to high traffic volume, reduced mobility, the security, and safety of the roadway infrastructure. The low-temperature properties of pavement, the resistance to fatigue cracking, and the improved high-temperature properties of old pavement are affected when the pavement is exposed to saline water. The increased salt concentration on the asphalt decreases the penetration and ductility of the pavement while increasing the softening point of the pavement. The HMA pavement deteriorates at the early stage when water flows on the surface of the road or when the salted water exists on the pavement. Although applying road salt and performing truck plow on the pavement can accelerate the severity of the potholes on the pavement, the deterioration of the most asphalt pavement is due to traffic volume, aging, temperature and other climate conditions like precipitation. When the water flows along the surface of the pavement, the pavement tends to lose its performance and service lifetime due to stripping, raveling and cracking on the pavement. The effect on the Marshall strength and the severity of the surface damage on the pavements increases when there are both water flow and salts on the pavement. The severity of the deterioration and the deterioration rate tends to increase during the freezing-thawing cycle. DIAICs leads to moisture damage on the pavement. The pavement experienced degradation of the mixture, the debonding of the pavement mixture, softening of the pavement, and the stripping. DIAICs reduce the surface tension of the water and lead to HMA pavement’s long-term retention of moisture due to its hygroscopic behavior.

It is vital for the pavements to withstand the movement of the soil. Trees tend to increase the soil movement and lead to cracking and distortions on the pavement.

**Recommendations**

By comparing the practices on mixture design used in Maryland, Virginia and Pittsburgh, some improvements can be made to the mixture design criteria. Like Maryland, Pittsburgh can determine the number of gyration and the maximum aggregate size of the HMA mixture based on the traffic level (to be determined specifically for the City of Pittsburgh) and ESALs. Also, the PG selection process can be changed to be based on traffic speed, specified ESALs range, and rutting history of the pavement. In addition, mixtures with different aggregate sizes like 4.75mm, 25.0mm, and 37.5 mm can be considered for specific pavement.

Some practices used in Virginia may also be adopted in Pittsburgh. Pittsburgh can use specific mixtures types or asphalt binder for locations (such as intersections, parking area, buses, etc.) with specific purposes. Thin Hot Mix Asphalt Overlay (THMACO) can be used to preserve the pavement condition. Also, Pittsburgh can use Open Graded Drainage Layer (OGDL) to provide the pavement drainage system. Pittsburgh can consider the service life, specified ESALs range, the pavement type, pavement layer location, and the total thickness of the pavement to choose an appropriate PG of the asphalt binder.

Although each of the HMA mixture types has its advantages on the pavement performance, few scientific reports compare the effects of different HMA mixture types on the pavement performance. Brown and Cooper found that more permanent deformation occurs on the pavement with gap-grade mix compared to
the pavement with the dense-graded mix. However, no scientific report compares the effects of all HMA mixture types to the pavement performance. Therefore, scientific studies and experiments are required to study the effects of each different HMA mixture types on different conditions. Only with careful and complete experiments, it would be possible to recommend Pittsburgh with particular types of mixtures.

Since the moisture content of the aggregates leads to the massive impact on pavement performance, controlling and managing the moisture content of the aggregates stockpile is essential. Currently, the moisture content of the aggregates stockpile in Pittsburgh is controlled by making the steep slope. Pittsburgh may consider covering the aggregates stockpile to manage the moisture contents of the aggregate stockpile.

The advantages of parallel flow dryer and counter-flow dryer are stated. However, the effects of the parallel-flow dryer and the counterflow dryer on the pavement performance are not studied. Therefore, the recommendation of dryer types can be made after the study of the effects of these two dryers on the pavement operation.

The wet collectors and the baghouse have been discussed previously. However, their effects on pavement performance are not studied. Therefore, the effects of each emission control system must be studied to make any recommendation.

Although the advantages of each type of plant are studied, the effect of each different type of plant on the pavement performance is not studied. Therefore, it is vital to conduct reports studying the effects of plant type on the pavement performance to make a recommendation. Based on the study, the plant type used in Pittsburgh can be evaluated.

The use of larger aggregates for the mixture can provide the better pavement performance. Therefore, Pittsburgh can consider using more 19mm maximum aggregates size and use of larger aggregates sizes like 25mm and 37.5mm. Also, Pittsburgh can also consider the change the mixture with 9.5mm maximum aggregate size to the mixture with 12.5 mm maximum aggregate size. The effects of maximum aggregate size on other distress like fatigue cracking on the pavement must be studied to make changes in current practice.

Since the surface texture of the aggregates influences the internal strength of the mix, internal friction of the mix, skid resistance of the mix, and the bond strength between aggregates and asphalt binder, the surfaces texture of the aggregate used in Pittsburgh must be studied in order to make any changes in the aggregate used in the Pittsburgh. With the change in the aggregate based on the surface texture, the pavement performance may be improved. The article shape and the angularity of the particles used in Pittsburgh must be studied to make any changes to the aggregates used in Pittsburgh. Since the fine aggregate (manufactured sand) use in Pittsburgh is currently type B, Pittsburgh can consider using type A of the fine aggregate as the quality of the fine aggregate affects the pavement performance.

In order to prevent the rutting, fatigue cracking, and thermal cracking on the pavement, the asphalt binder must be carefully selected, and the asphalt content of the mixture should be carefully identified.
Since the resistance of rutting and cracking react differently as the asphalt binder content changes, it is crucial for Pittsburgh to study the percentage of rutting and cracking occurring on the pavement to make changes to the asphalt binder percentage in the mixture. Also, the effects of asphalt binder on several other distress must be studied to find the effects of asphalt binder to the pavement performance.

When selecting the PG of the asphalt binder, Pittsburgh can consider choosing the asphalt binder with higher 7-day average maximum pavement temperature and lower 1-day minimum pavement temperature. However, the scientific research on the effects of asphalt binder on different distress like moisture damage must be conducted.

The RAP used in Pittsburgh is collected through the milling methods. In order to make any suggestion to the current method of collecting RAP, the study on the effects of different methods of obtaining RAP (milling, full depth pavement demolition, waste) to the pavement performance must be conducted.

Pittsburgh is currently using the 15% of the RAP in the mixture. The effects of RAP on the pavement performance are shown for the mixture with more than 20% of RAP, Pittsburgh could consider the use of more RAP (20% or more) in the mixture. However, Pittsburgh would need to consider the fact that the use of more RAP can lead to negative impacts on the pavement performance. Therefore, it requires the study on the effects of the different amount of RAP in the mixture to the pavement specifically in the Pittsburgh. Pittsburgh also needs to use asphalt binder with softer grade when the mixture with more than 20% of RAP is used on the pavement. Also, Pittsburgh must consider the fact that the thickness of the overlay impacts the effects of RAP to the pavement performance. Therefore, Pittsburgh can consider using the mixture with the RAP on the overlay with thick thickness.

Currently, the stockpile of RAP in Lindy Paving is not covered although an in-line processing is used, and the stockpile has the steep slope. Since the moisture content of the RAP hugely impacts the pavement performance, Pittsburgh must consider covering the stockpile of RAP for the pavement performance. Pittsburgh is currently using flow boy and dump trucks for the transportation of the mixes to the paving site. Pittsburgh can use MTV for the transportation of the mixes to the paver. The MTV prevent segregation during transfer support the continuous paving operation, eliminate the potential of trucks bumping into the paver, preserve consistent mat temperature, and improve the smoothness of the mat. In order to recommend the truck type for the transportation of the mixtures, the study on the effects of different trucks type on the pavement performance must be conducted. The scientific report must study the segregation of mixture and the change in mixture temperature for each truck types. Also, there must be a study comparing the pavement performance when the truck delivers the mixture and when the MTVs are used.

Pittsburgh currently uses Raytek Gun to check the temperature uniformity of the surface. However, it is hard to visualize the temperature of the pavement’s surface with Raytek Gun. Checking the consistency of the surface temperature is important as the quality of mat and the amount of distresses changes. By checking the temperature of the surface, especially on the longitudinal streak, it is possible to prevent the cracks happening on the longitudinal streak. Therefore, Pittsburgh can use the infrared camera for checking the temperature uniformity of the surface.
Kick paddles can prevent the segregation of the mixture during the placement process and the creation of the longitudinal streak at the pavement. It requires the continuous maintenance to replace the damaged or missing kick back paddles installed since damaged kick paddles can create more cracks and longitudinal streaks on the pavement. Therefore, Pittsburgh can consider the use of kick paddles during the paving operation.

In order to make changes to the current paving practice used in Pittsburgh, the reports studying the effects of different joint geometries (like the natural response of material geometry, cut joint geometry, and wedge or taper joint geometry) to the pavement performance must be conducted. Also, the effects of different surface preparation techniques, like the use of chip seal and slurry seal, the use of the patch, and the use of milling and tack coats, to the pavement performance must be studied.

Pittsburgh must research specific and scientific effects on the pavement service lifetime and performance due to different materials types of the base layers. Also, there lack of scientific studies reporting the effects of rail tracks and utility cuts on the pavement performance.

While there is no specific scientific report studying the effects of buses on the pavement, the effects of buses are similar to the effect of heavy trucks on the pavements since the buses are also heavy vehicles that have the passenger car equivalent of 851 passenger car.

Currently, there is a lack of reports on the influences of tree saps and snow plowing on the pavement performance. Also, it is crucial to specifically research the pavement performance under Pittsburgh weather condition although there are studies on the impacts of climatic condition on the pavement performance. Also, there should be separate research on the effects of several climatic factors on the pavement condition and its performance.

Part of the objective of the research was to compare the pavement practices used in cities of Maryland and cities of Virginia with the current practices used in Pittsburgh. Except the mix design, other information cannot be collected as there was no response from the representative or the document cannot be released to the public. Therefore, in the near future, Pittsburgh could contact cities in Maryland and Virginia for the data and information on plant manufacturing process, aggregate sources, asphalt/crude sources, recycling process, paving process, base layer materials, and climatic condition to conduct the comparative analysis in the future.

In addition to scientific studies and experiments of pavement design, manufacturing and paving process, it is also recommended to adopt a data-drive approach to understand the underlying mechanism of pavement degradation with massive data collected over the last decade. Those data include, but are not limited to, the paving time and process of pavement, time, location and outcomes of pavement inspection and retrofit, weather conditions, traffic conditions, drainage design, bus operation, roadway design, roadways surface conditions, and any other factors that potentially affect pavement deterioration and in-service time. The data-driven research, if successful, enables accurate models of pavement deterioration over specific location and time, as well as for short-term and long-term prediction of pavement quality, allowing decision making of pavement design, paving and retrofit projects. It may be more cost-effective than traditional physical experiments of pavement materials.

26