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16. Abstract

Sidewalks are a hallmark of modern society and support commerce, recreation, and foster a sense of community pride. Kansas City Missouri has a substantial sidewalk replacement program with a number of sidewalks over 100 years old. The purpose of this research project was to provide a framework for the evaluation of new sidewalk types and benchmark current practices to aid sidewalk surface selection from sustainability, constructability, and biomechanical standpoints. Considerations included challenging site locations where high slope, lifting from root heave, and tree cover create less than optimal conditions for pedestrians in the winter and result in a disproportionate amount of maintenance and public complaints. The evaluated surfaces included standard concrete, low carbon footprint concrete, stamped concrete, and two rubberized surfaces. The concrete test section had a 49% reduction in CO_2 while addressing all of the common durability distresses in Kansas City. The flexible test section provided better biomechanical measures than the control and better snow melting ability when unshaded. Most interestingly, the stamped concrete section produced biomechanical measures more similar to a flexible pavement with good frictional characteristics. Results allow improvements to day-to-day sidewalk materials and selection of materials and surfaces with better performance in less-than-ideal locations.

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EVALUATION OF NON-TRADITIONAL SIDEWALK OPTIONS FOR REDUCED LONG-TERM COST AND IMPROVED PUBLIC ACCESSIBILITY

Final Report
April 2023

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The assistance developing and supplying the concrete mixture by Century Ready Mix and Steve Settle is appreciated as well as Gunter Construction for working with the research team for construction. The research team would like to thank Karoleen Alexander with Rubberway for the engagement and discussion of material application and specifics to make the project a success. We extend a special thank you to Jon Lamanes and Olsson Associates for donating the personnel and equipment for profile testing. Lastly, thank you to students Jordan Salt, Suellen Batista, and Sean Bryant for the assistance in data collection.

1.0 INTRODUCTION

Sidewalks are a hallmark of public infrastructure development and a key component for access and safety. Additionally, highly functional sidewalks encourage better health, reduce pollution, reduce crime, and foster a stronger sense of community. This is especially highlighted during COVID where sidewalk utilization significantly increased. The GO KC sidewalk program was approved in 2017 to evaluate, repair, and replace sidewalks over a 20-year timeframe. The systematic sidewalk inspection program prioritizes sidewalks from a 1 to 5 rating throughout the City. Sidewalks in KCMO are almost exclusively Portland Cement Concrete (PCC) over a limestone gravel base placed directly on the native soil (Section 2301). Currently asphalt is not allowed as a permanent sidewalk (Section 2302). Sidewalks experience a defined set failure mechanisms including:

- Uplift – Heaving caused by roots or expansive soil.
- Settling – Depression caused by destabilization and erosion of the base and subgrade.
- Cracking – Fracture caused by overloading or excessive uplift or settling.
- Faulting – Elevating differences between sidewalk panels typically caused by root heave or gravity movement of sidewalk sections on a hill characterized by loss of load transfer between slabs.
- Spalling – Surface scaling of the concrete, typically a result of water added during construction and application of deicer salts.

While the GO KC program provides a routine and robust methodology for assessing current sidewalks, the program is not designed to evaluate the potential for new sidewalk options. This project leveraged UMKC's pavement and human gait motion mobility expertise to provide a comprehensive process for KCMO Public Works to compare new sidewalk materials and products from both material and public well-being perspectives. This research assessed suitability of new sidewalk types and materials for use in KCMO by:

- Longitudinally tracking performance seasonally,
- Providing specification language guidance for selection, installation, and acceptance,
- Providing a selection matrix to aid choosing appropriate locations for new sidewalk types, and
- Providing a cost-benefit analysis to aid determining locations where new sidewalk types would be most applicable.

The ultimate goal is to provide information to aid selection of potentially safer and lower cost sidewalk alternatives.

Note: Generic material names and material classes are utilized throughout the report as appropriate. Particular product names are only included when the particular product has unique characteristics not possessed by other products in the class. Mention of specific names does not represent an endorsement by the research team or the City of Kansas City Missouri.

2.0 DESIRABLE SIDEWALK CHARACTERISTICS AND MEASUREMENT METHODOLOGY

The research data collection was comprised of two components, pavement performance evaluation from a material perspective and human/pavement interaction from a biomechanics perspective. The combination was utilized to develop a working systematic selection approach.

Microtexture is used to characterize pavement surfaces at the smallest scales (depths up to 0.5 mm, and widths less than 0.5 mm), and is most closely aligned with coefficient of friction. Baseline static friction/microtexture was determined using dry and wetted static surface drag testing as shown in Figure 1 modified for contact using a rubber shoe sole. Microtexture or CoF is particularly important for winter performance of sidewalks installed on slopes.

Figure 1. Drag meter testing for friction and microtexture

Macrotexture, or surface roughness, is used to characterize pavement surfaces at medium scales. ISO defines surface roughness at depths between 0.5 and 20 mm, and widths between 0.5 and 50 mm. Macrotexture was measured using the volumetric technique according to ASTM E 965, in which a known volume of sand is applied to the surface and the coverage area is measured as shown in Figure 2. From the volumetric sand patch test a macrotextural mean profile depth can be determined according to ASTM E1845. Macrotexture is an important consideration for storage of deleterious materials within the pavement without negatively impacting performance. A large macrotexture provides space for tree/leaf litter and snow compaction under pedestrian foot traffic.

Figure 2. Sand patch testing for macrotexture (Top left rubber path, Top right Rubberway, Bottom left stamped brick tested over joint, Bottom right stamped brick tested between joints)

Surface profile (bumpiness) of the sections was determined using a walking dipstick profilograph. The flatness of the sections was then determined using ASTM E1155. A representative 20 feet was testing with opposing passes to determine the average profile disregarding the site slope. Figure 3 shows profile testing at the concrete control site. Flatness is an important component to help minimize tripping due to toe strike.

Figure 3. Dipstick profile testing for flatness

While pavement surfaces from a safety perspective are often defined by only coefficient of friction (CoF), especially for human interaction, a variety of different surface textures will produce similar CoF. However, the actual human interaction may be vastly different. For this study EMG muscle sensors and accelerometers were used to determine the amount of muscle activation and body movement from a person moving across the pavement as shown in Figure 4. Less muscle activation means moving across the surface is a less taxing activity for the individual and lower core body acceleration means there is less of an impact on joints.

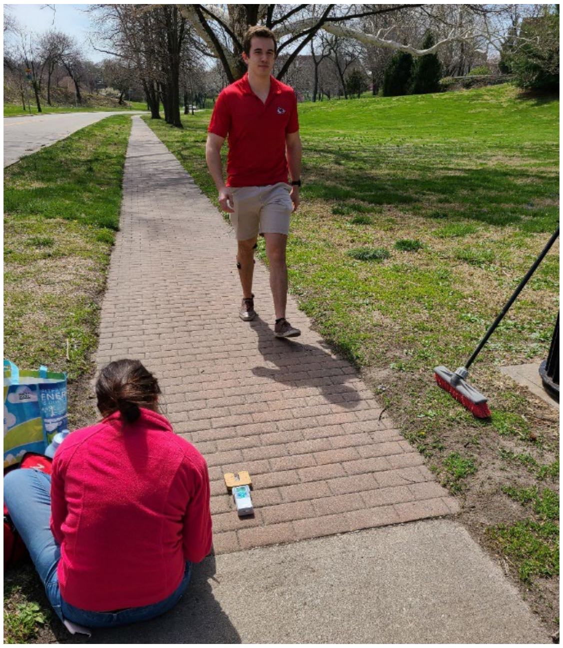


Figure 4. Biomechanical gait testing on the stamped brick test section

Table 1 shows the relative importance of pavement characteristics as related to the site characteristics. Conventional concrete sidewalks function well under flat, dry, and unshaded conditions. Assuming appropriate concrete durability specifications have been applied, which are outside of the scope of this research, the vast majority of issues for sidewalks occur when installed in steep slope areas, areas with lifting tree roots, and areas with high shading. These factors often occur together with high slopes and high shading presenting potential icing issues in the winter and tree root heave often occurring in areas with high shading. Reducing root heave will reduce trip potential and improving surface texture will reduce slip potential. The evaluation test sections were selected to represent areas which experience multiple issues.

Table 1. Material selection considerations for various site conditions

Site Characteristics	Micro texture	Macro texture	Wet Friction Loss	Resistance to Faulting
High Slope	H	H	H	M
High Tree Cover/Root Heave Potential	M	H	M	H
High Shading	M	H	H	L

3.0 EVALUATION TEST SECTIONS

The research analyzed two new test sections and three existing sections located roughly between 39th street and 43rd street along Gillham road. Figure 5 shows the location of the test sections. The existing sections included a standard concrete sidewalk in good condition (Control Concrete), stamped brick concrete sidewalk in good condition (Stamped Brick), and the asphalt walking path around Gillham Park which has a rubber surface coating similar to a school track surface (Rubber Path). The two test sections included a flexible surface (Rubberway) and rigid surface (Research Concrete).

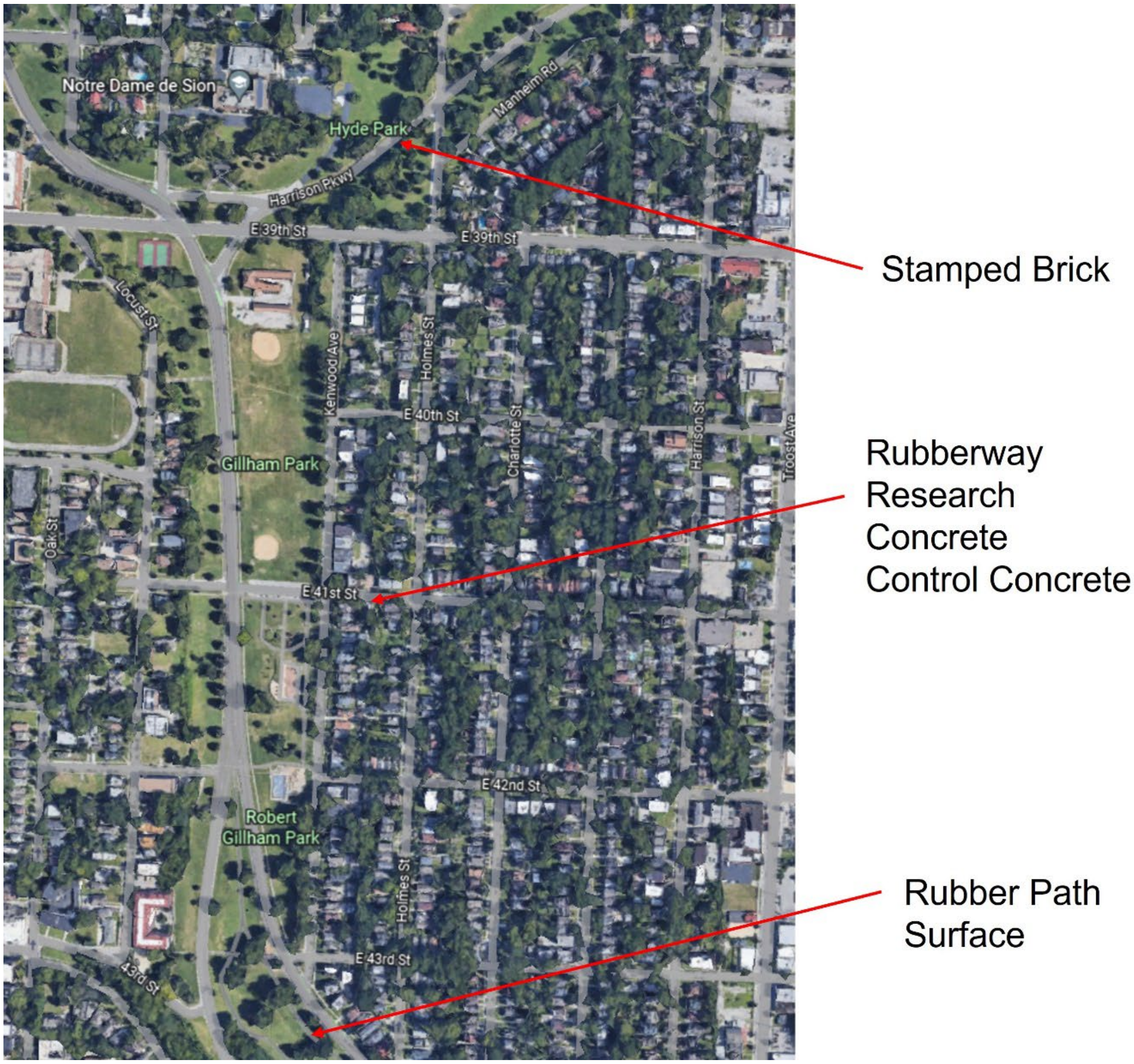


Figure 5. Location of Test Sites (google maps)

The research test section site is show in Figure 6. The test site was selected because it represented a combination of all of the most challenging sidewalk installation locations. The existing sidewalk had significant (>6 inches) faulting due to root heave. Any damage to the existing roots would destabilize the tree shown and require removal. The site has a significant slope and has tree cover. The site is located on the south side of the street so direct winter sunlight exposure is limited.

Figure 6. New sidewalk surface test section located along 41st St. (Image looking to the southwest)

3.1 Rubberway Test Section

Rubberway is a recycled tire chip, coated with a protective paint which provides coloration, and held together using a polyurethane binder. While multiple similarly equivalent products are available, Rubberway is the market leader and has a production facility in Springfield, MO and responsive to requests for information. The marketed advantages are:

- High recycled material content from waste tires,
- Permeable to reduce winter ice build-up and ponding during rain,
- Permeable to allow water to infiltrate to adjacent tree roots,
- Permeable to allow evaporative cooling and reduce the urban heat island effect,
- Flexible to reduce joint wear,
- Flexible to reduce faulting where root heave occurs,
- No specialty equipment required for placement, and
- Ability to be colored to match existing sidewalks or proposed decorative materials.

Figure 7 shows in initial site preparation for the Rubberway test section on the south-eastern portion of 41st st. The two Sycamore trees visible in the figure had caused significant faulting of the existing concrete joints to a degree that the local homeowners had painted the faulted edges bright pink to warn pedestrians. The most eastern tree was leaning substantially over the roadway and clearly supported by the offending roots (Figure 8). Removal of the near-surface roots would have likely caused the tree to fall into the roadway. As a permeable pavement, a drainable aggregate base (Figure 9) is required to aid stormwater storage and infiltration. This location possessed a high slope, a large amount of shading, and significant root heave. The combination represents a worst-case for sidewalk performance and an ideal test section.

Figure 7. Rubberway section looking east prior to installation of aggregate base materials

Figure 8. Tree root protected (left) before aggregate base installation, (right) after Rubberway placement

Figure 9. Rubberway section during aggregate base installation

Figure 10 shows the site prepared for the Rubberway installation. The aggregate base was placed over the top of the offending roots with minimal disturbance. The Rubberway test section was completed in two placements one week apart. Although the specifications and construction guidance recommended a multi-paddle mortar mixer, due to rental availability a standard concrete mixer was used for the first placement (Figure 11). Rubber chips and polyurethane binder were added to the mixer and mixed until uniform. The mixture was then transferred to the site using wheelbarrows and screeded with a straightedge. As shown in Figure 12, the concrete mixer did not sufficiently blend the materials and balling was observed. Once level a concrete finishing trowel was used to smooth the surface (Figure 13).

Figure 10. Rubberway section prior to installation

Figure 11. Day 1 Rubberway mixing

Figure 12. Initial installation of Rubberway section

Figure 13. Finishing Rubberway section with hand trowel

Immediately upon placement, bubbles and expansion of the polyurethane was observed. Although the site had been covered with plastic for several days before placement, Rubberway representatives explained moisture from the aggregate base was negatively reacting with the polymer binder. Figure 14 and Figure 15 show initial bubbling and expansion of the polyurethane binder. After approximately half the section placement it was decided to stop and resume after an anti-foaming component was obtained. The second half of the test section was placed a week later using the recommended mortar mixer and anti-foaming agent. No balling or bubbling was observed. The remainder of the document description contains two Rubberway sections, a good and a bad. The bad section refers to the first placement and the good to the second.

Figure 14. Bubbling of Rubberway as polyurethane reacts with ground moisture

Figure 15. Continued bubbles forming prompting a halt of day 1 placement

3.2 Research Concrete Test Section

The concrete research test section was designed to address all of the common distresses observed in Kansas City along with providing a reduced carbon footprint and improved resiliency. To combat durability cracking (d-cracking) the coarse aggregate was a local high-quality limestone from the Cedar Valley ledge, used in an optimized gradation with the fine aggregate component. To combat alkali silica reactivity (ASR), calcium oxychloride formation, and reduce embodied carbon, 38% of the cement was replaced with blast furnace slag (24%) and Class F fly ash (14%). A combination of synthetic and natural air-entraining admixtures was utilized to ensure a quality air system for good freeze-thaw durability. Polypropylene macro fibers (3 pcy) were included to reduce joint faulting and help maintain functionality should the section experience unintended vehicular traffic. The thickness was reduced from the standard 4 inches to 3 inches to help further lower embodied carbon and the surface was cured with a sodium silicate evaporation retarder to reduce surface scaling and resistance to deicing salts. The coarse aggregate maximum size was reduced to ½ in. to accommodate the thinner section. A mid-range water reducer was used to maintain workability of 5-6 inches at the water to cementitious materials ratio (w/cm) of 0.44. Each aspect presents a known individual improvement to concrete durability and addresses the most common local issues. At the time of placement this was the first performance engineered concrete mixture (PEM) used for a sidewalk installation.

A common consideration and complaint by concrete finishing crews when dealing with fiber-reinforced concrete is the decreased workability and inability to install tooled construction joints. The research test section (125 ft) placement occurred with an hour to discharge and place the concrete, and an additional hour to complete finishing and jointing operations, both are in the expected production for a conventional sidewalk of these dimensions. Figure 15 shows successfully installing tooled construction joints. Since adding water to concrete, either to the truck or to the surface, presents one of greatest negative impacts to long-term durability, appropriate workability was maintained with chemical admixtures rather than allowing the contractor to add water.

Figure 16. Hand tooling joints in the research concrete section

4.0 INITIAL TEST SECTION PERFORMANCE

The test sections were observed over 18 months for durability and winter behavior. The section profiles are shown in Figure 17 as determined using a walking profilograph. The test sections on 41st street had the greatest slope. Table 2 presents a summary of the textural, biomechanical, and profile results. All three aspects strongly influence how humans safely interact with a pavement surface and are independent. The Rubberway section had the highest macrotexture while the concrete research section had the least. The stamped brick section had the highest coefficient of friction (CoF) and the Rubberway section had the greatest loss of friction between wet and dry. The FF flatness is related to the smoothness of the profile and not the total elevation change. High FF numbers mean the surface would be safer for persons with low foot mobility and tend to shuffle, such as elderly persons. The concrete sections had the highest FF numbers. An example of the biomechanical data is shown in Figure 18 for the control concrete on the left and the good Rubberway section on the right. The higher relative waist acceleration for the control concrete and lower muscle activity shows that more of the impact is transferred to the body than the comparatively lower acceleration and higher muscle activity of the Rubberway section. While location and person-specific, generally more muscle activity indicates active firing of muscles and more engagement with the surface.

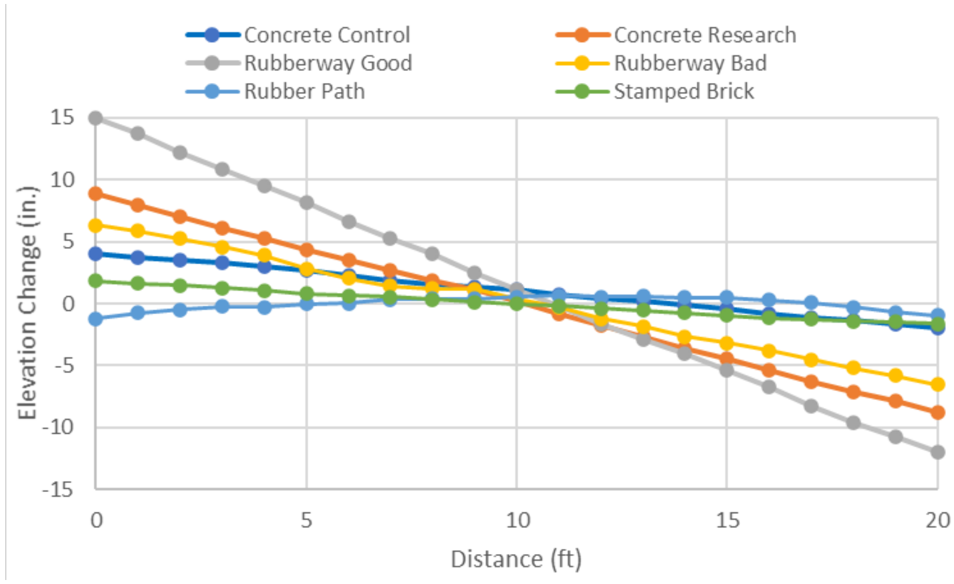


Figure 17. Test section profiles

Table 2. Surface Textural Assessment

Surface	Macro-Texture MTD (mm)	Micro-Texture COF (Dry)	COF (Wet)	COF loss (%)	Flatness FF
Old Concrete Control	1.10	0.9	0.8	18%	10.82
Rubberway (Bad)		0.7	0.7	0%	5.16
Rubberway (Good)	2.08	1.0	0.7	28%	7.72
Concrete Research	0.43	0.9	0.8	13%	14.26
Stampled Brick	1.42	1.2	1.0	14%	25.14
Rubber Path Surface	1.85	1.0	0.9	11%	8.11

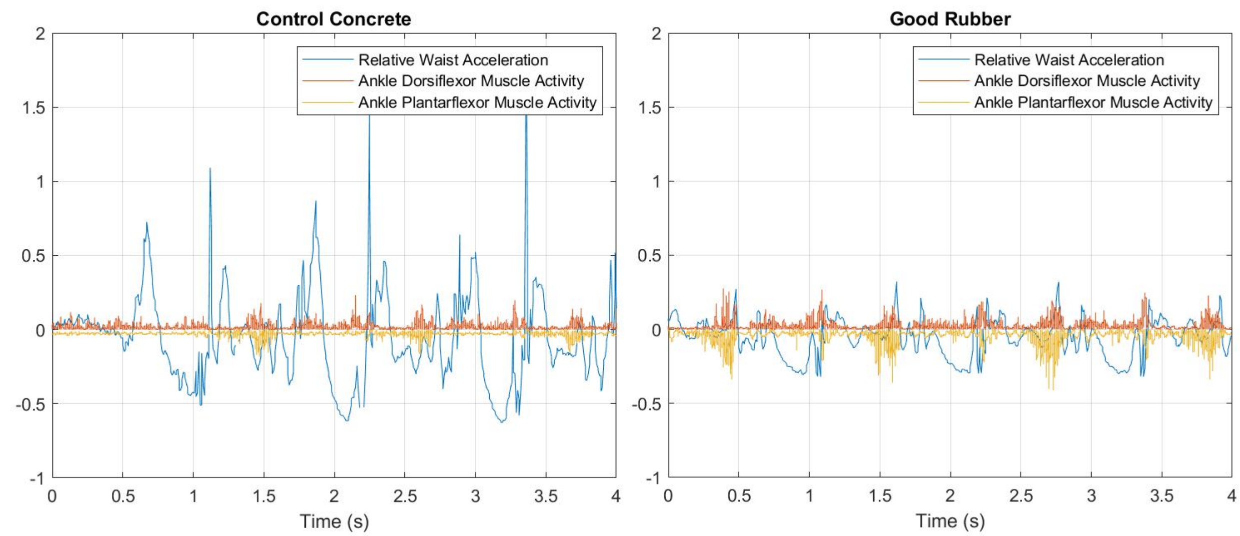


Figure 18. Example biometric data

4.1 Test Section Observations

Rubberway

The Rubberway test section was mostly shaded by the home located on the south side of the installation. The section was rarely shoveled after snowfall, which was consistent with the conventional sidewalk section also present on the property. Snow and ice buildup and melting on the shaded portion was similar to the adjacent grass strip located between the sidewalk and the street. The lowest and westerly portion of the test section was not shaded and melted snow and ice much more quickly than the adjacent concrete as shown in Figure 19. As previously described, the Rubberway placement occurred across two different days because of placement challenges encountered during the first placement. The initial section mixed using the concrete mixer and without the anti-foaming agent had poor durability and started raveling immediately after opening to foot traffic (Figure 20). The section placed according to the manufacturer's recommendations had good performance at the time of publication. While the product is marketed as permeable, the steep slope exceeded infiltration testing recommendations and is not reported. If there is interest in using Rubberway as a permeable pavement, an additional flat test testing should be installed to verify the product meets design requirements.

The Rubberway test section contained 2,600lbs of recycled tires which results in 322lbs of CO_2 sequestered. The installation requirements were similar to concrete placement from a manpower standpoint with the additional time required during mixing offset by no finishing after smoothing. The material for the test section was obtained at a discounted rate with the actual material cost around $10/sf. The current cost range for the installed materials is $15.50 to $18.50/sf.

Figure 19. Unplowed Rubberway section where section exposed to sunlight melted and shaded did not

Figure 20. Current state of the bad Rubberway section (Oct 2022)

Research Concrete

The research concrete section was similarly generally not shoveled during most of the winter (Figure 21). No differences in melting or icing were observed as compared to the concrete control section or other surrounding concrete sections. As a note, roadways are typically designed for an average deicer (rock salt) application rate of 250lbs per lane*mile or 0.004 lbs./sf. As applying this amount of deicers by hand is difficult, typically homeowners and business owners apply significantly more. Figure 22 shows an example of a locally, much higher application rate. High concentrations of deicer salt can cause scaling and surface damage on concrete. Although this particular mixture was placed in October and relatively young during the first winter which would make it highly susceptible to deicer salt scaling, the densifying curing compound may helped prevent damage. At the time of publication, the concrete section was in perfect condition.

The concrete research section had good strength of 3,851psi at 7 days and 5,818psi at 28 days and flexural strength of 668 psi at 28 days. These values are consistent with high quality concrete used in heavy traffic installations. The cost for materials and installation was approximately $2/sf and the material cost itself was 12.5% higher than the baseline concrete mixture. The current cost range for material and installation is $13.50 to $16.50/sf. The concrete research section had a 2,002 lbs. or 49% reduction in CO_2 compared to the control with anticipated significant improvement to durability.

Figure 21. Concrete research section unplowed during winter

Figure 22. Region of high salt application which can result in surface scaling

5.0 SELECTION DISCUSSION

As with all construction decisions there is a tradeoff between cost, durability, and constructability. Table 3 shows a relative comparison of the different surfaces across the non-biomechanical factors as compared with the current standard concrete sidewalk section where:

- Cost – Material cost where up is a higher cost (less desirable)
- Constructability – Ease of placement where up is more difficult to construct or different than the currently utilized conventional broomed concrete surface (less desirable)
- CO_2 – Carbon footprint on a square area basis where up is higher (more desirable)
- Wow – The pavement level of interest to the public where up is better (more desirable)
- Reliability – Anticipated long-term durability where up is better (more desirable)

Table 3. Selection consideration by surface

Material	Cost	Constructability	CO2	Wow	Reliability
Conventional Concrete	↔	↔	↔	↔	↔
Stamped Concrete*	↑	↑	↔	↑	↔
Rubber Path Surface	↑	↑	↑	↑	↓
Rubberway*	↑	↑	↓	↑	↓
Research Concrete*	↔	↑	↓	↔	↑

Notes: Stamped concrete installation is roughly double the conventional concrete; the targeted application for Rubberway is to protect/maintain trees; and the research concrete could also be applicable for curb and gutter

The particular sections have more applicability in certain locations. The Rubberway material may be more applicable for locations around tree wells and where root heave is a concern due to the flexibility and air and water access to the roots. The research concrete may be more applicable for locations where highly durable materials are needed such as heavy salting, plowing, or inundated freezing and thawing with curb and gutters a good candidate in addition to sidewalks. Many different stamping patterns exist for concrete and this project evaluated one style and location. Stamping and decorative concrete have additional considerations such as workability, timing, and curing that are not covered in this document. Considerations for stamping must include an ADA-compliant pattern. At the time of publication KCMO is installing stamped concrete on Independence Ave. and has noted generally twice the time and cost to install which may limit stamped sections to those with particular slip and fall concerns. The rubber path surface is a bonded overlay to existing asphalt or concrete. As such, durability to routine plowing is an additional consideration not discussed herein.

In 2021 KCMO placed approximately 500,000 sf of sidewalk. Converting from conventional concrete to the concrete research mixture would result in a reduction of over 1 million pounds of CO_2 annually which is equivalent to taking about 100 cars off the road. The other aspects present in the mixture of highly durable aggregate, good air void system, ternary cementitious materials, and macro fibers were all designed to produce an extremely durable material with a long lifecycle. Additional lifetime CO_2 and cost reductions would be anticipated due to the extended time period between reconstructions over the conventional concrete mixtures. According to MIT, on average a mature tree captures 50 lbs. of CO_2 per year which could be incorporated into the carbon sequestration of Rubberway or other permeable surfaces through longitudinal verification of tree inventory.

An initial systematic approach was assembled to compare the various pavement textural and biomechanical components. The presented Figure of Merit (FOM) uses the raw data obtained from the testing, however future adjustments could include preferential weighting of the various components to better tailor to owner or community needs. The associated textural and biomechanical data collected from the sites was compared using in the following equation.

$$FOM = \frac{Mac * LR * FF}{BMA}$$

Where:
Mac = Macrotexture
LR = Microtexture loss ratio when wet
FF = Flatness number
BMA = Total area under the waist acceleration curve

Using the data collected, all surfaces except the poor quality Rubberway section, had better textural and biomechanical performance than the concrete control section. Of particular interest, the stamped brick section possessed additional macrotexture and had a higher microtexture than the control concrete. While stamping provided an improvement to smoothness and surface elevation consistency, the texture provided by the stamped pattern created additional plantar flexor muscle activity and reduced core acceleration, effectively making the surface appear softer to the individual. The rubber path surface had high microtexture, little frictional loss when wet, and good damping of acceleration due to the soft surface composition which also produced a highly desirable surface. Using these factors and weighting, the stamped brick, rubber path surface, and good Rubberway section had better performance than the control concrete (Figure 23). The research concrete had similar performance to the control concrete, which was expected and the bad Rubberway section worse. It is important to note that the scale is unitless and this technique provides a general ranking. The actual values are not scaler (i.e., the stamped section is not 16 times better than the control), moreover a reasonable approach to compare performance.

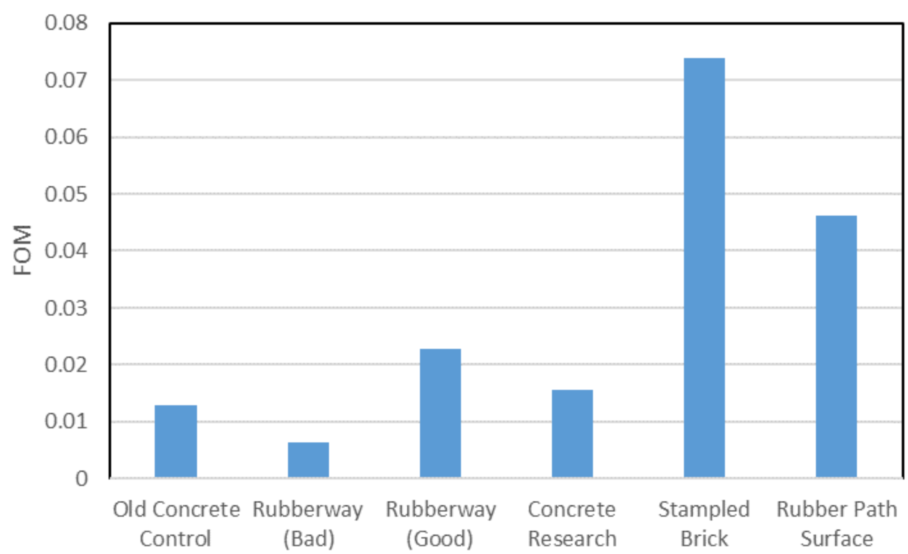


Figure 23. FOM results for the tested data set

6.0 CONCLUSIONS AND RECOMMENDATIONS

Sidewalks represent a needed and fundamental component of modern society. In many cities in the US, Kansas City included, the standard is four to five inches of concrete over a few inches of crushed aggregate. This typical section works well in many situations, however where trees and steep slopes are concerned the typical concrete section can result in faulting. With a broader National conversation on rebuilding infrastructure for the future, sidewalks are an interesting microcosm of the broader infrastructure network allowing considerations for carbon footprint, sustainability, resiliency, equity, access, and safety. Summarizing the question presented by Kansas City, Missouri, *if we are building back sidewalks why can't we install something that benefits the local environment, minimizes global climate change, and promotes better health outcomes by providing a safer surface for all people?* As a start, in this study two test sections were constructed and compared with three existing sidewalk and pathway types. A broad assessment of constructability, environmental, surface textural, and biomechanical components were evaluated.

The concrete research section was designed to possess superior durability and significantly lower CO_2 than the currently utilized materials. The combination of a thinner section (3 inches versus the standard 4 inches) and polypropylene macro fibers should result in reduced faulting (unwanted elevation change) when lifted by root action or cracking from unanticipated loading. The textural behavior was similar to the conventional concrete control section as was the human-pavement interactions. The concrete used in the research test section would be a good long-term strategy for reducing sidewalk replacement. A unique observation of the study was the beneficial biomechanical properties of the stamped brick section evaluated. While this study is limited to one textural pattern at one location, it is clear that surface textures other than the standard broomed surface have the ability to improve the human-pavement interaction. Future beneficial research is recommended to evaluate different available surface textures and determine the optimal combination of desirable characteristics for safety with ease of installation. Ultimately a highly durable, low CO_2, and safer surface could be implemented throughout the City.

The second test section represented a significant deviation from the norm. The Rubberway test section was a unique surface comprised of recycled tires which is much more flexible and should reduce the likelihood of roots to lift towards the surface and unwanted faulting should root heave occur. The reduced stiffness of the surface created beneficial biomechanical performance while the incorporation of waste tires provided some embodied CO_2 benefits.

While designed as an initial pilot, the project results met all the project objectives and provided a needed baseline for evaluation of future materials. Low CO_2 and highly durable concrete can be easily supplied and constructed by local professionals. The lessons learned by piloting the Rubberway section showed the importance of installation recommendations when overlooked and durability and performance when followed. Biomechanical assessment of pavement surfaces is not common, and the testing included in this project produced striking and never-before observed results of the influence of surface texture on safety measures. Modifications to the standard concrete mixture can produce a significant reduction in CO2 and additional surfaces and material types can be selected to provide preferential performance when trees, environment, and human interactions are prioritized.

APPENDIX A: CONSTRUCTION DOCUMENTS

Rubberway

Rubberway® Pavement Installation Manual

Produced by Rubberway, Inc.

This Manual is specific for:

Kansas City MO

The following document describes the Application and Practice of a Technology for the Installation of a (project specific) Pervious Rubber Pavement System. The information is proprietary to Rubberway, Inc and is provided for the use of the Recipient and the Recipient's employees only, and according to the terms of the Limitations of Use Agreement between USSA, Inc. and the Recipient. USSA, Inc., Rubberway, Inc. and any of its subsidiary companies, will not be held responsible for the resulting installation, unless a Company approved Certified Technical Training Director has been hired to train and perform oversight on the installation.

DISCLAIMER: USSA, Inc., Rubberway, Inc. and or any of its affiliates or subsidiary companies, accept no responsibility for the resulting installation, in terms of a successful application or durability or any other performance or appearance characteristics. Certified technical training directors are available for hire, to enable interested parties to practice the installation of this system with onsite technical training support.

Introduction

Rubberway® Pervious Pavement

Rubberway Pervious Pavement is an alternative to traditional pavement and asphalt systems. This system is constructed from a recycled rubber granule free of fiber and steel, bound by an environmentally safe, non-toxic bonding agent. This creates a very porous, open grid surface that allows for rapid rainwater dispersion and storm water management.

The porous nature of Rubberway Pervious Pavement makes it easy for rainwater to drain through, reducing storm water runoff and allowing water to disperse through the permeable subbase. This rubber pavement system is resilient and provides a low slip, ADA, comfortable and safe walking jogging surface, yet firm enough to be suitable for more high impact use from strollers, wheelchairs, and occasional golf carts and maintenance vehicles.

Rubberway Pervious Pavement is an easy to install single layer system that can be used for a variety of applications including pathways, sidewalks, walking and jogging trails, school blacktops overlays, medians, tree wells and more.

The rubber granules used in this system are made from recycled, metal-free tire rubber encapsulated with a UV Inhibitor color coat compound. Rubberway Pervious Pavement can be customized in terms of color, porosity, and rigidity to create the perfect solution for each specific project.

Equipment

The mixing equipment required for successful application of the system is simply a wheelbarrow for small areas up to 100 sf. mixing within the wheelbarrow should be done with gloved hands, ensuring the rubber is thoroughly coated with binder.

A larger (9 or 12 CFT) capacity Whiteman mortar mixer or equivalent mortar mixer is useful for mixing and pouring in square footages above 100 sf. The mixer can be any reasonably good quality commercial mixer capable of handling the heavy consistency of the rubber mixture.

Checklist of Tools

☐ Blower/Broom - to remove leaves and debris

☐ Shovel - for mixing in a wheelbarrow, or used to compact

☐ Rake - for mixing materials in wheelbarrow, or used to compact

☐ Inexpensive brushes - to prime surrounding concrete

☐ Variety of steel hand trowels and bull floats - to level, finish and compact material

☐ Clean up rags

☐ A few pieces of 2' x 4' or 6' wood to screed and cut to meet the intended thickness of the system

☐ Disposal Container/Bags

☐ Tarp or heavy plastic sheet - To protect the wheelbarrow/mixer & ground around the site. If rain is expected while curing, thick 4 mil. plastic sheeting will be needed to cover the installation area.

☐ Cleaning solution for equipment - solvent (TXIB), diesel fuel, Bio Premier Maintenance solvent

☐ Wide masking tape and brown paper - to mask off the perimeter of installation as needed

☐ "Caution" tape, safety signs, cones, stakes, etc. - to protect the area

☐ Battery operated digital scale (up to 50 lbs) - for measuring weight ratios of materials

☐ (2) 5 gallon measuring pails and (2) 1 gallon pails - for measuring weight ratios of binder

☐ Extra buckets - for trowel cleaning solution, leftover loose material, etc.

☐ Gravel compactor (optional) - for compaction on CMB sub base preparation if applicable

☐ Protective gear - thick, industrial quality rubber gloves, long to elbows for the person at the mixer

☐ Boxes of throw away disposable latex gloves for the trowlers /finishers

☐ Disposable plastic jump suit that can be thrown away (optional)

☐ Protective eye wear

Note: Everyone involved in the installation process should wear gloves, protective eye wear, long sleeve shirts, old jeans, and work boots. The bonding agent is very sticky.

Materials

Rubber Bits – Can create a flexible, permeable rubber pavement system when bound together.

Our systems use recycled rubber that is derived mostly from truck tires and granulated to create a unique matrix of sieve sizes to create our Rubberway® pavement systems.

The rubber bits are then color coated with a proprietary process to encapsulate the rubber. We use an above industry standard percentage amount of color coat.

We offer a variety of color options and sieve sizes. The rubber mix comes as bits, crumb, or granules. Our color options are Brick Red, Golden Brown, Mahogany Brown, Tan, Nutmeg, Beige, Mid Gray, Green and Black. Some colors may have higher costs and may require minimum orders or longer lead times.

Bonding Agent

The proprietary bonding agents used in the process are materials specifically formulated for the purpose of binding these systems. The binders used are moisture-curing, the rate of cure being affected by temperature and humidity. Increased temperatures and increased humidity accelerate the curing time. Always keep containers firmly closed when not in use and preferably out of direct sunlight in warm climates. TDS are available for each product by request. We also incorporate an extra additive in many of our binders which offers an Anti-Foaming characteristic (AF). This additive may not prevent foaming altogether but will very definitely help aid with foaming issues that can arise in moist environments. This added feature in our binders can be requested to be removed and will reduce the cost of the binder.

Rubberway® Envirobinder 3000 or 6000 are non-hazardous amber hue bonding agents. The 3000 is used as a primer or is the standard binder of choice for mixing with rubber on single layer Pervious Pavement systems for tree wells and walkways for strollers, wheelchairs

The 6000 provides a hard-ridged surface finish, when combined with rock, yet offers some flexibility and is recommended for light vehicular traffic, like maintenance vehicles, golf carts and high use areas.

A variety of Rubberway® binders have been designed to perform optimally in different climates. Temperature and moisture variability affect the cure time of the binders. For example, higher temperatures and higher moisture or humidity will shorten the cure time whereas lower temperatures and lower humidity lengthen the cure time. The addition of accelerators will shorten the cure time as well. Please consult a Rubberway® specialist for technical guidance on the binder that is right for your area's climate and your intended application.

PolyStar Enviro Binder 2000- This is a base only binder for multi-layer systems.

PolyStar EnviroBinder 3000- Our standard premium amber hue binder suitable for use in a variety of temperatures and conditions. This binder offers high levels of elasticity and tensile strength and provides good force reduction on impact when combined with rubber. * Rubberway® 3000 will have an amber hue and alter light colors like Mid Gray.

PolyStar EnviroBinder 4000- Our premium clear binder suitable for use in a variety of temperatures and conditions. This binder is UV-stable and does not discolor over time.

PolyStar EnviroBinder 5000- A premium clear binder used for areas exposed to chlorine, maintenance as well as repairs. This binder is suitable for use in a variety of temperatures and conditions. This binder is UV-stable.

PolyStar RR Binder 6000- An amber hue binder designed to be mixed with rubber, stone or rubber and stone. The RR 6000 bonding agent produces a more rigid, firmer finish then our standard bonding agents and provides lower levels of elasticity to prevent stones from popping out in freeze thaw environments.

PolyStar EnviroBinder 7000- A moisture cure clear coating and binder for use in the repair and refinishing of bonded rubber granules. Due to the higher hardness from our standard clear envirobinder 4000, the 7000 is recommended for spot repairs and as a thin layer recoat application for reconsolidation of a weathered rubber surface. The materials can be applied using a conventional airless spray or roller applicators

PolyStar RR Binder 8000- A premium clear binder with UV stabilization designed to be mixed with rubber, stone or rubber and stone. The RR 8000 bonding agent produces a Rigid, firmer finish then our standard bonding agents and provides lower levels of elasticity to prevent stones from popping out in freeze thaw environments.

PolyStar EnviroBinder 9000- This is a premium varnish and various pigments are available for roll applied color coat options and to revive the color in older surfaces.

General Product Information

All Rubberway PolyStar Binders are solvent-free, moisture-curing, one component, polyurethane binders designed to produce poured-in-place surfaces. It is recommended that PolyStar Binders are tested by the user in advance on a large-scale application, to determine the suitability of the product for the specific application. Curing takes place at ambient temperature by reaction with atmospheric moisture. Higher temperatures, moisture, and the addition of accelerators shorten the cure time. An ambient humidity of 40-80% is recommended for appropriate cure. Relative humidity below 40% may extend the cure profile and may necessitate the addition of water and/or accelerator. Please consult your Rubberway® representative for advice on specific amounts of accelerator and/or water.

Do not use water to speed up curing with the Rubberway® Polystar 4000 any moisture on the installation surface may cause the material to foam with micro bubbles.

Safety Considerations

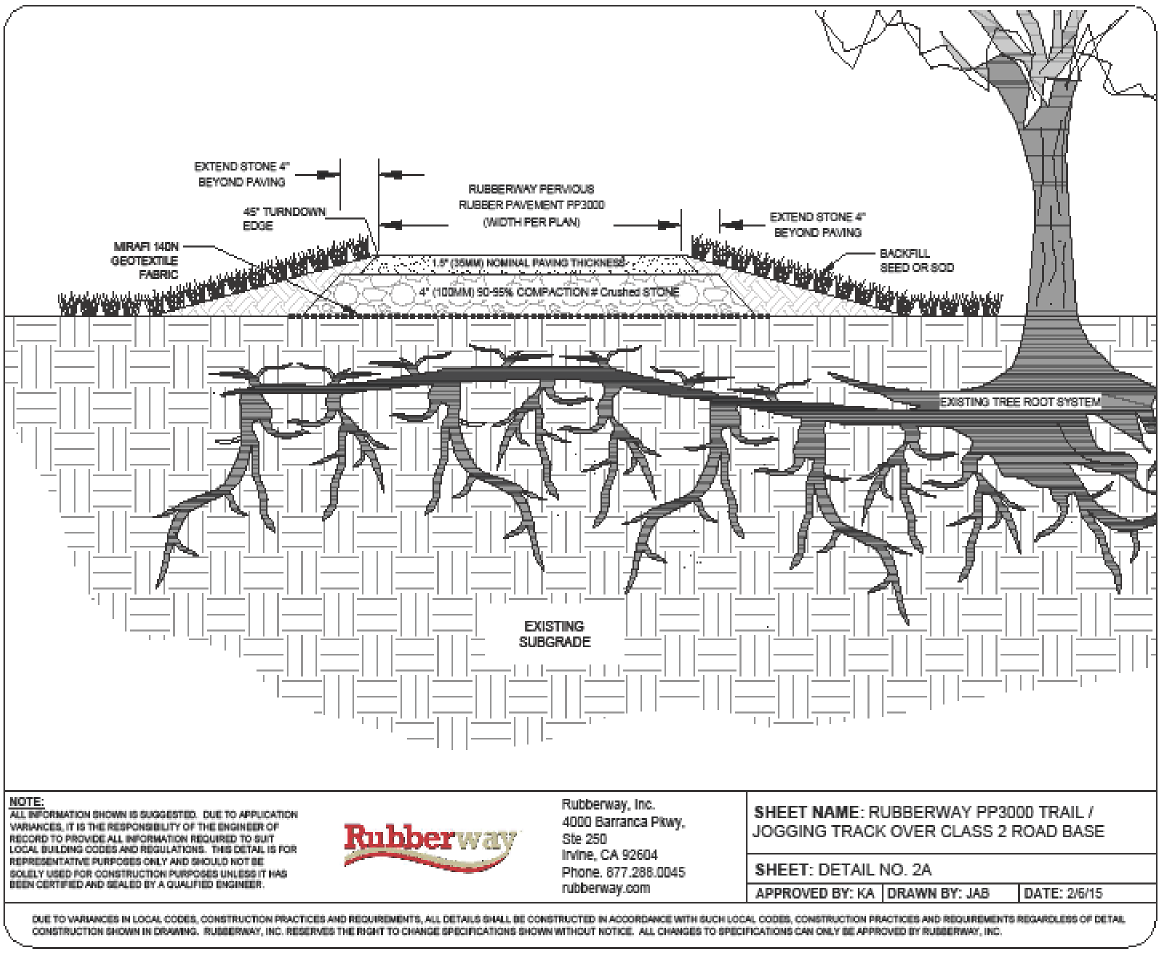
The rubber products are not toxic and are non-allergenic. However, there may be an amount of dust present, which could adversely affect people with respiratory problems or allergies. For prolonged exposure, the use of dust masks or respirators may be required. Please refer to MSD sheets for more information.

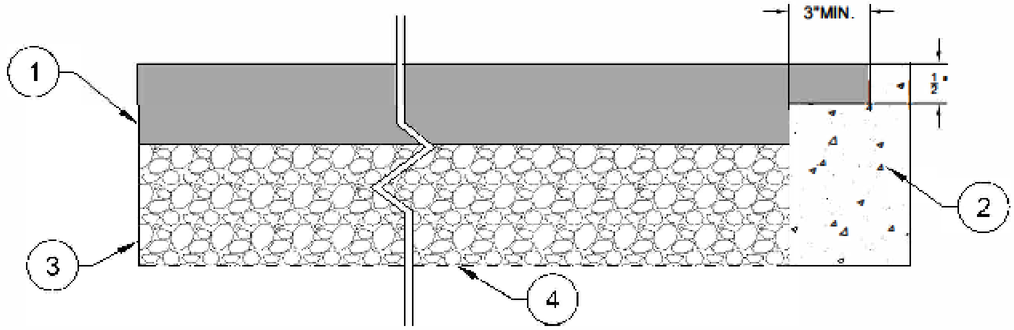
The binders, primers and sealers are mildly toxic and consequently may be hazardous. It is important that eye protection be worn and protective gloves and respirators are recommended, particularly for those with allergies.

In the interest of cleanliness and safety, we recommend protective suits, respirators and gloves, and insist on adequate eye protection, with face contacting flanges to protect against splashes or drips.

Detail Drawing- Example

Additional Detail Options are Available





NOTES:

1. RUBBERWAY PP3000, SINGLE POUR **SYSTEM**, RUBBER WITH **ENCAPSOLATED COLOR COAT** 1.5" DEPTH TOTAL THICKNESS
2. CONCRETE BORDER
3. 4" MIN. SUB-BASE (CONCRETE, ASPHALT, OR 95% COMPACTED AGGREGATE INSTALLED IN 2-2" LIFTS), SLOPE 2% MAX
4. MARAFI 140N GEOTEXTILE FABRIC

TOTAL THICKNESS OF SYSTEM IS BASED UPON MANUFACTURER'S RECOMMENDATION

NOTE: RUBBERWAY PP3000 RUNNING TRACK, JOGGING TRAIL	Rubberway, Inc. 4000 Barranca Pkwy, Ste 250 Irvine, CA 92604 Phone. 877.288.0045 rubberway.com	**SHEET NAME:** RUBBER WAY RECOMMENDED CURB MOUNT (NEW CONSTRUCTION) **SHEET:** DETAIL NO. 10 **APPROVED BY:** KA | **DRAWN BY:** JAB | **DATE:** 7/14/16

DUE TO VARIANCES IN LOCAL CODES, CONSTRUCTION PRACTICES AND REQUIREMENTS, ALL DETAILS SHALL BE CONSTRUCTED IN ACCORDANCE WITH SUCH LOCAL CODES, CONSTRUCTION PRACTICES AND REQUIREMENTS REGARDLESS OF DETAIL CONSTRUCTION SHOWN IN DRAWING. RUBBERWAY, INC. RESERVES THE RIGHT TO CHANGE SPECIFICATIONS SHOWN WITHOUT NOTICE. ALL CHANGES TO SPECIFICATIONS CAN ONLY BE APPROVED BY RUBBERWAY, INC.

Surface Preparation

For optimum results, the substrate upon which the pervious pavement system will be installed must be properly prepared. The working temperature needs to be 55 degrees and rising. Best is 60-80 degrees. The sub-base cannot be frozen or really wet.

Suitable substrates for Rubberway® Pervious Pavement in order of preference are:

a) Crushed and compacted stone and gravel aggregate (generally class 2 permeable #57 stone topped off with a ½" of #8 and compacted to 90 percent for storm water management criteria or a Crushed miscellaneous Class II road base compacted 95% is also acceptable)
b) Concrete
c) Asphalt

The principal requirement is that the substrate must be firm, stable and allow water to drain for a porous system. The minimum compaction rate acceptable with a stone base is 90%. In the case of concrete and asphalt, drainage rock or gravel should be provided at each side of the walk or path.

For Pervious Pavement over tree roots, concrete and asphalt should be removed and compacting slightly reduced to allow moisture to penetrate to the tree roots.

Borders

The borders, or edges, of the pervious pavement should be contained by a concrete curb, sure lock steel edging or temporary removable wood form borders when doing a finished edge without borders or a beveled at a 30-45 degree angle and back filled to protect the edges from future damage.

If you are installing over an existing root base and you create a slope, or bridge, you must trim the roots enough around the perimeter of the area being installed so that you may create a 1 ½ - 3" deep, 45 degree beveled edge. If adhering to concrete or steel edging, the borders must be primed at the inside perimeter edge of the curb at least 1 ½" inches deep, up to 30 minutes prior to installation. If using removable forms, prior to installing the rubber, wipe the inside perimeter of the removable forms with vegetable oil as a form release to help with sticking.

Mixing and Blending

Pervious Pavement Bits (Recycled Rubber Granules Silver/ Grey), Standard Binder (Rubberway 3000); The graph on the right demonstrates options with varying thicknesses

(SEE PREPARATION and MIX ILLUSTRATIONS ON THE FOLLOWING PAGE 9 -11)

Mixing Ratios will need to be calculated prior to blending

Recommended System is 1.5 " Thickness for Rubber Pavements

NOTE: The rubber bags weight is = 50 lbs each
The Binder 3000 weight is 43 lbs in a 5 gallon pail

TOTAL THICKNESS (INCHES)	SINGLE LAYER RUBBER (LBS/SF) Recycled Rubber Bits.	SINGLE LAYER BINDER (LBS/SF) 20% (Rubberway 3000)
½"	1.625	.325
1"	3.25	.65
1.5"	4.87	.97
2"	6.5	1.30
2.5"	8.125	1.625
3	9.75	1.95

Mix Rubber and Binder 3000
Mix the weight of rubber bits x 20% binder

BY THE FULL BAG-
(Colored Rubber comes in 50 lb bags): 2 bags= 100 lbs (x) binder mix of 20% binder = 20 lbs of Rubberway 3000 binder or 10 quarts. (Rubberway 3000 pails have 43 lbs of binder per 5 gallon pail)

Combine the above weights of materials putting rubber in first while the mixer is on. Add the proper ratio of binder to the rubber mix in the mixer. Mix for 1-1.5 min. (60- 90 seconds) Make sure all the rubber materials are completely coated and shiny with the polyurethane binder.

Installation Process

1) Prepare the Sub-Base

Prepare the specified sub-base (requirements vary by project). This may include installing curbs with keyway notch, fiberglass dowels or Sono tubes if required, and around trees, temporary wooden borders, steel, or other edging.

Figure 1: Prep the area *Figure 2: Add base and Sono tube* *Figure 3:Add Base in lifts and compact*

2) Make Sure Area is Ready

The working temperature needs to be 50 degrees and rising. Best is 55-80 degrees. Make sure all areas are completely dry or dried out after a rain. The sub-base cannot be frozen or wet. Any moisture evaporation from the sub-base can cause foaming of the binder which can cause micro bubbles. Prep and protect all adjacent areas surrounding the work area to be performed.

FOR SIDEWALKS, TRAILS OR TREEWELLS USE THESE OPTIONS AS NOTED BEOW

Figure 1: Concrete curb with Steel Edging

Figure 2: Temporary wood forms

Figure 3: Line the base rock if forms are not used

Figure 4: Existing curb with existing sidewalk

3) Prime the Edges

Prepare the edges and/or subbase of the installation by priming it with binder to ensure adhesion of the rubber to the concrete, asphalt, curb, or steel edging. This should be done up to 30 minutes prior to installation. If using temporary wood forms do not prime the interior edges.

With temporary wood forms we recommend coating the interior of the wood forms with vegetable oil prior to the application of the rubber.

4) Mix the Rubber Granules with the Binder

Once the volume of recycled rubber granules and the required weight of binder have been calculated, measure the rubber granules and place in an already spinning mortar mixer. Add the proper amount of binder and allow it to mix thoroughly – generally 1 minute in the mixer (60-80 seconds) until rubber is completely coated with binder. Make sure each batch is consistent on the mixing time.

For small applications around 100 sf, a wheelbarrow can be used, and the materials blended and mixed by hand using a shovel. If mixing in a wheelbarrow, mix thoroughly until you see a glistening of urethane coating on all the materials.

5) Pour the Rubber Pavement Mix

Pour the mixed material into the prepared installation area directly from the wheelbarrow in small piles spread a foot apart.

It is important to move quickly to avoid premature curing and setting of the mix. The material must still be loose and fluid as it is poured into the area so it can be troweled to a surface finish without creating trowel marks. The open time is generally 2-3 hours but is dependent on the type of binder used and the ambient conditions.

6) Spread the Rubber Pavement Mix

Troweling / Finishing Work

A) Once the material has been dumped into the installation area, it is spread evenly and quickly using the trowel to approximately the top edge of the edging or a measuring stick to gauge the thickness. For larger areas, it may be more convenient to use a rake to spread the material.
B) As the material is spread it is lightly tamped. Do not add pressure. Material is removed or added until the mix is flush with the top of the containing edge, or when the desired thickness is met. At this time, you can also create an angled beveled edge finish if preformed edging is not used.
C) Do not compact the materials, just lightly spread into place with the trowel, swiping the trowel in between strokes with TXIB, Xylene, MEK, Bio Premier Maintenance Solvent and a towel to remove excess material on trowel.
D) Once the single layer has been spread, tamped, and leveled to be flush with the top edge of the curb, repeat the troweling process, and spot check the area again for trowel marks and inconsistencies.

NOTE: During the spreading and troweling process, the mix will build up on the trowel. Remove it frequently and between strokes, using the troweling rag dipped in TXIB Finishing Solvent



7) Clean the Mixer or Wheelbarrow

Clean the mixer and wheelbarrow to remove residual crumb rubber granules to avoid contamination. Do not allow any material to dry in the mixer overnight, it will make cleaning the mixer more difficult.

NOTE: Make sure to have someone responsible to clean the up the mixer. Allocate 45 minutes to an hour for this task. Thoroughly clean the mixer and wheelbarrow to remove residual rubber to avoid contaminating them permanently. Use Scrapers and Big Handheld

Nylon Bristle Brush for cleaning the Drum of the mixer. Do not allow the material to dry overnight in the mixer. It will become a nightmare to clean out.

Curing

Protection during Curing

If heavy rain is anticipated within a few hours after application, cover with plastic sheet. Do not have the plastic sit directly on the uncured rubber surface. The system cannot get wet while curing or it may foam. If the temperature drops 20 degrees within 2 to 3 hours of curing you are risking that the system could crack and the system installation will fail. In the spring and fall in the cooler climate areas of the country try to stop installing by 4 pm to avoid this potential risk. Or two hours before dusk. The Rubberway 4000 binder takes longer to cure in the cold temperatures. Below 65 degrees may take up to 4 days.

Set up cones/stakes, temporary barricades, signs, and caution tape around site to prevent damage while curing area.

Testing for Cure

To test the installation to ensure it is sufficiently cured for use, test it with your hand, it should be firm and not tacky to the touch. This is generally 24 hours after installation. During cooler months, curing process will take longer than during warmer months.

Materials used for roll coat Maintenance

DISCLAIMER: USSA, Inc., Rubberway, Inc. and or any of its affiliates or subsidiary companies, accept no responsibility for the resulting installation, in terms of a successful application or durability or any other performance or appearance characteristics. Certified technical training directors are available for hire, to enable experienced cement mason

Research Concrete

The concrete utilized for the research was a proprietary mixture, however all components are readily available and able to be supplied by all concrete producers in the Kansas City region. Within the framework of Performance Engineered Mixtures (PEMs) the most significant potential update is the inclusion of requirements in the specification sufficient to achieve the desired properties, simply you get what you ask for. Rarely does concrete fail because of low compressive strength, however often compressive strength is the only evaluated quality assurance method. The following performance measures and testing for durable sidewalk concrete in Kansas City.

A. Slump (ASTM C143): 5.0 in. - 7.0 in. Actual slump shall be kept as low as possible, consistent with proper handling and thorough compaction. Slump shall not exceed 7 inches unless authorized by the design professional. A lower slump will be required for curb and gutter (hand or machine-placed). Slump can only be adjusted using water if the water to cementitious materials ratio of the adjusted mixture does not exceed the approve design. Otherwise, slump and slump retention should be modified using water reducing agents and hydration stabilizers.

B. Slump retention: Slump shall be greater than 5 in. at all times during discharge. Water may not be added mid-truck to loosen the mixture.

C. Air content (ASTM C231): 5.0% - 8.0%. While air content determined using ASTM C231 does not indicate bubble size or spacing, in general concrete with air content tested above 5% have good performance. Air contents less than 4% are considered marginal and should be rejected. In the future or for locations requiring a higher degree of reliability, Super Air meter or ASTM C457 hardened air testing may be appropriate.

D. Compressive Strength (ASTM C39)

1. 24 hours – 1,000 psi

2. 7 days – 2,500 psi

3. 28 days – 5,000 psi

E. Flexural Strength (ASTM C78): 28 days – 650 psi

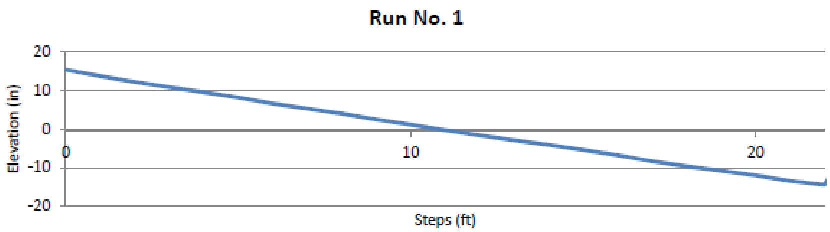
F. Surface Resistivity (AASHTO T358): >50 kohm*cm at 90 days

G. Minimum Residual Strength (ASTM C1399): 125 psi. EXCEPTION: Residual strength testing requirements may be omitted if the proposed mixture contains greater than 3.0 pcy of a polypropylene macro-type of fiber.

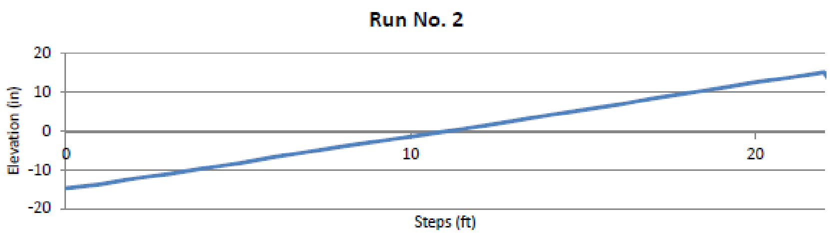
APPENDIX C: SECTION PROFILES

Rubberway

The following profile is the lower, western Rubberway section which was in good condition.

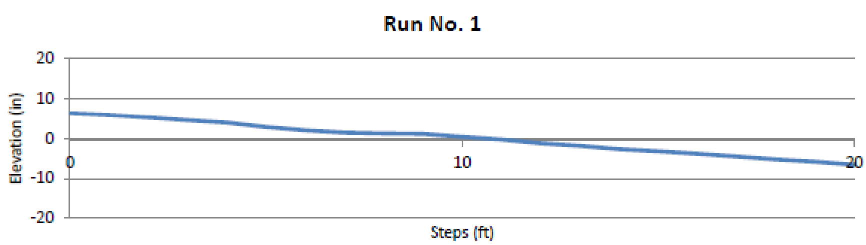


FF= 7.82 <9.88-5.76> FL= 0.85 <1.14-0.56>

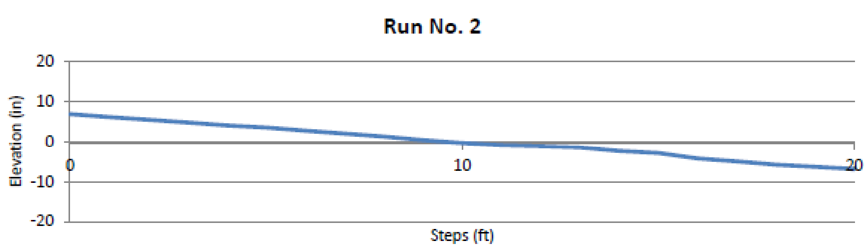


FF= 7.62 <9.63-5.61> FL= 0.87 <1.18-0.57>

The following profile is the upper, eastern Rubberway section which was in poor condition.

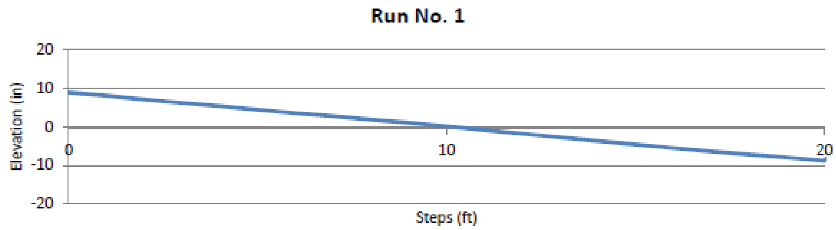


FF= 5.41 <6.90-3.92> FL= 1.67 <2.28-1.05>

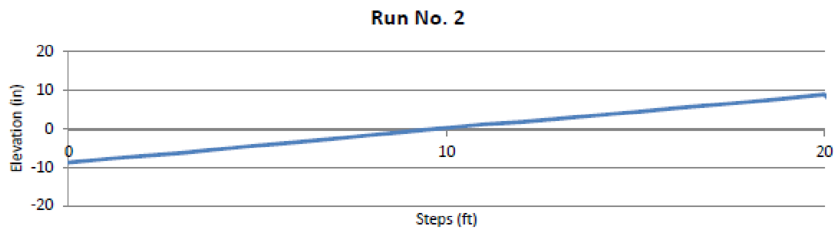


FF= 4.90 <6.24-3.55> FL= 1.62 <2.22-1.02>

Research Concrete

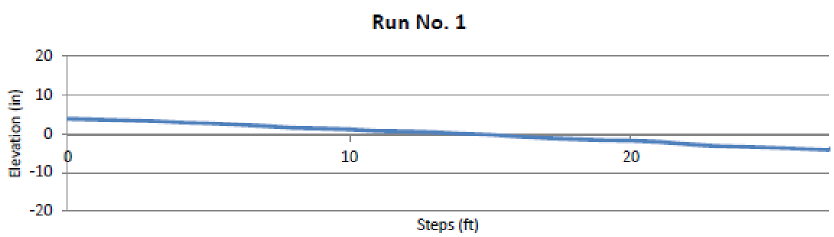


FF= 17.00 <21.68-12.32> FL= 1.35 <1.85-0.85>

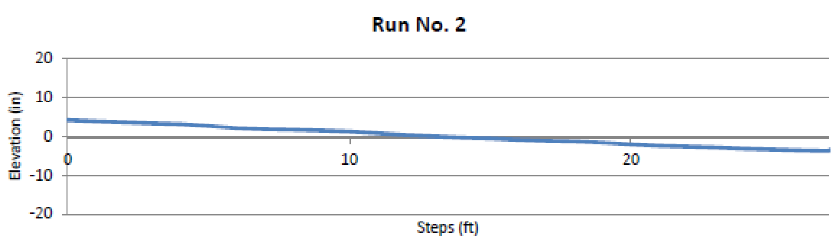


FF= 11.51 <14.68-8.34> FL= 1.36 <1.86-0.86>

Control Concrete

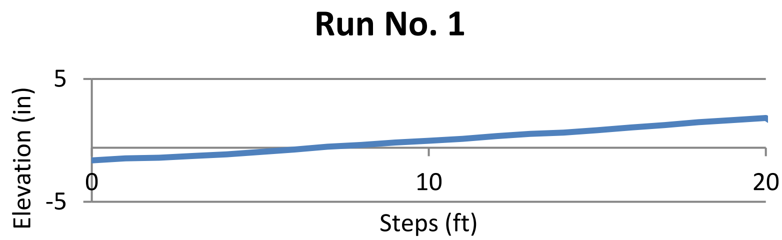


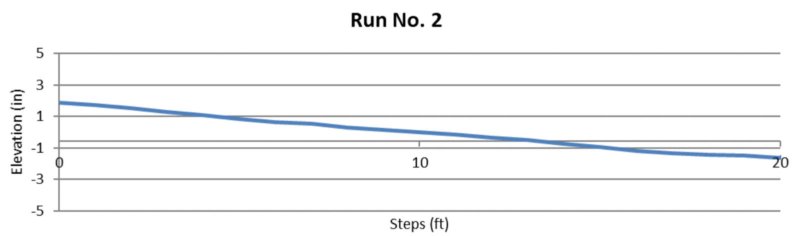
FF= 9.85 <12.22-7.49> FL= 3.39 <4.39-2.38>



FF= 11.79 <14.62-8.97> FL= 3.36 <4.35-2.36>

Stamped Brick Stamped Brick





Rubber Path Surface