Technical Report on Cost Effective Long Lasting Streets

Selecting Street Maintenance Materials for Maximum Durability and Safety

Introduction and Conclusions

The largest single investment of public funds most communities make is their investment in streets. Local governments are expected to make decisions that protect this substantial investment through the implementation of long-lasting and cost-effective street maintenance programs. This report discusses one key element of an effective street maintenance program, the use of surface treatments to prolong the life of underlying pavements. The report will review the available scientific literature, with a focus on the affect the color of aggregates used in surface treatments has on the longevity of the roadway and community safety.

Roadways are typically constructed of hot mix asphalt pavement, which is a combination of coarse and fine aggregate (rock and sand) mixed at high temperature with asphalt oil (a black tar-like product). The hot mix asphalt cools and is compacted in the roadbed, resulting in a durable, structurally sound roadway. As the pavement is exposed to weather elements, particularly heat, sunlight, and precipitation, the pavement can deteriorate. Sunlight and oxygen cause the asphalt oil in the pavement to become brittle, losing its ability to hold the pavement together. Water intrusion has often been found to be the cause of roadway failure through a variety of physical mechanisms.

Failing roadways can be reconstructed or overlaid with new hot mix asphalt, but those are significant construction operations that are costly and disruptive to traffic patterns. In order to prolong the life of the original pavement, most public agencies use surface maintenance treatments. While these treatments can make the road look "like new," their real advantage is the restoration of the skid resistance of the road surface and the protection of the underlying pavement from weather related deterioration.

Slurry seal and chip seal maintenance treatments are two popular and effective ways of extending the life of original hot mix asphalt pavement. These surface coatings serve as a protective layer for the underlying pavement.

Slurry seal and chip seal differ in composition and application, but both are comprised of a combination of a binder (emulsion or oil) and aggregate.

Based on research conducted by the University of California, Lawrence Berkeley Laboratories, among others, there are many advantages to public agencies using slurry and chip aggregate that is light in color (i.e., grey instead of black). While some people may prefer the black roadway color to lighter colors for aesthetic reasons, there is no question that use of lighter colored slurry aggregate results in increased durability of the underlying pavement, increased safety for nighttime driving, environmental benefits, and reduced cost.

Research Review Regarding Advantages of Light-Colored Aggregate Use

Graniterock has been in the construction materials business since Valentine's Day, 1900. The Company installed the first hot mix asphalt plant in California in the 1920s. Throughout its history, Graniterock has supported the development of specifications based on sound scientific evaluation. This Research Review, and the accompanying technical papers and references, are intended to provide City and County leaders and public works departments with sound technical background information to use in establishing appropriate specification requirements for street maintenance bid documents.

I. Slurry Seal, Chip Seal, and Cape Seal – how these maintenance treatments differ and how each support longer life for original hot mix asphalt pavements.

There are three popular ways to provide a protective layer on top of hot mix asphalt to extend the life of the underlying pavement.

Slurry Seal consists of a mixture of emulsified asphalt, aggregate, water and specified additives mixed in the proper proportions. The mixture is applied over the existing pavement. Slurry seal will seal surface cracks, stop raveling and loss of materials from the underlying asphalt matrix, make open surfaces impermeable to air and water, and improve skid resistance. Its timely application will help reduce surface distress caused by oxidation of the asphalt and embrittlement of the paving mixture.

Chip Seal is the application of an emulsified or asphalt binder to the street surface, followed immediately with the application of crushed aggregate "chips." Chip seals, also known as oil and screenings, aggregate seal coats, and armor coats, are surface treatments. They are most valuable as a preventive maintenance tool, especially for roads that receive light to medium traffic.

Cape Seal is a two-step process of applying a chip seal followed by a slurry seal. Cape Seal was developed as a means of preventing "rock loss" from chip seal applications by constraining the chips under the slurry seal.

II. Caltrans Slurry Seal Specifications – commonly accepted with good service results.

California's Department of Transportation (Caltrans) has developed widely used specifications for slurry seal materials and applications. They have been used by the state and many local agencies with excellent results. Caltrans' specifications define the appropriate sizes of the slurry seal aggregate, called gradation, as well as measures of aggregate durability and cleanliness (stated as "durability" and "sand equivalent"). Large aggregate cannot be held in place by the slurry emulsion. Similarly, aggregate that is too small would not provide acceptable coefficient of friction (avoidance of road slipperiness). Obviously, soft aggregate would not provide much resistance under vehicle tires. The Caltrans specification addresses each of these issues, resulting in slurry seal applications with good service lives. A copy of the Caltrans specification for slurry materials is provided in the "Caltrans Specification" tab.

One thing the Caltrans specification does not address is the color of the slurry aggregate. Aggregate can vary in color depending on the geophysical processes that that created the rock deposit. Aggregates can span the color spectrum from nearly pure white to nearly pure black. The Caltrans specification does not require that slurry aggregate be of any particular color. Nevertheless, there is a common misperception in road building industry that equates black color with quality pavement. This misperception is so common that material suppliers in some states commonly add lamp-black to hot mix asphalt to make their product appear more black, thus erroneously conveying quality.

Since slurry emulsion is typically black, initial applications of slurry seal (like new hot mix asphalt roads constructed with black asphalt cement) are black. As the emulsion is removed or worn off the slurry aggregate with traffic, the color of the slurry aggregate begins to show through. Slurry seal made with lighter colored aggregate will become light grey, and slurry seal made with black aggregate will remain dark. Some public agencies believe that roads that remain darker longer continue to "look new," and therefore will withstand a longer reapplication interval of the slurry. Equating black slurry sealed roads with quality or longevity, however, is a costly mistake.

III. Durability – does aggregate color impact service life?

In research conducted by Lawrence Berkeley National Laboratories and the Institute of Transportation Study at U. C. Berkeley, *Cooler Reflective Pavements Give Benefits Beyond Energy Savings: Durability and Illumination*, the authors found that light colored pavements are cooler, because the light color increases sunlight reflection. Cooler pavements result in longer pavement service life, and improved streetlight effectiveness (discussed below).

Hot mix asphalt pavements and slurry seals fail by a variety of mechanisms, some of which are temperature dependent. Pavement temperature, except in cold climates, is negatively correlated with pavement life. Higher temperatures age the asphalt products used in paving and cause the asphalt to become brittle or stiff. Hot mix asphalt pavements are better able to support traffic loads when surface temperatures are lower. "Rutting" describes a road surface in which vehicle wheel tracks form depressions in the pavement. The University of California determined that lowering roadway temperatures by 10^{o} C extends pavement life from rutting failure by a factor of 10. "Shoving," which occurs when pavement is "plowed ahead" at intersections by vehicle stopping action, was also reduced by a factor of 10.

Since lighter colored materials reflect heat and darker colored materials absorb heat, using a lighter colored slurry seal reduces not only the temperature of the slurry seal coating, but also reduces the temperatures transferred to the underlying original hot mix asphalt pavement. Researchers concluded that insulating the asphaltic concrete mat [hot mix pavement] with a reflective surface treatment (in the case studied a chip seal) in warm climates improves roadway durability.

Because hot mix asphalt pavements, as well as slurry, chip and cape seals, all incorporate asphalt (black) materials in their production, light colored aggregate is the remaining way to improve surface reflectivity and lower temperatures. Studies have shown that light colored aggregate does indeed improve reflectivity and lower pavement temperatures.

Summertime pavement temperatures have been measured in the San Francisco Bay Area. East Bay pavement temperatures ranged from 120^{o} F (49^{o} C) to 150^{o} F (65^{o} C) in the summer months. Solamanian and Kennedy (1993) predicted that maximum pavement temperatures at lower altitudes would exceed maximum air temperatures by 40^{o} F (25^{o} C). The actual temperatures found in the East Bay match the conclusions reached by Solamanian and Kennedy. Researchers have studied the condition of older pavements and found that pavement surfaces exposed to the higher temperatures age faster. Aging results in the paving materials becoming more brittle or stiff. The cause is a loss of volatile hydrocarbons (which provide the glue-like characteristic in emulsions and asphalts), and some oxidation and polymerization.

Researchers further have found that aggregate color does have a significant impact on sunlight reflectivity. Aggregate types in the Bay Area varied in reflectivity from 10% to 28%. Pavement temperatures are reduced 7^{o} F (4^{o} C) for each 10% improvement in reflectivity. Because aggregate covers a smaller percentage of surface area in slurry seals compared with chip seals, the temperature reduction is likely to be somewhat less in slurry seals. Reflectivity increases as the emulsion coating is worn away from the slurry aggregate surface exposing the light colored aggregate.

This research dispels the myth that darker-colored road surfaces equate with higher quality, longer-lasting pavement. To the contrary, agencies specifying dark colored slurry or chip aggregates are exposing their roadways to unnecessarily high heat, resulting in premature failure from rutting, shoving and other causes. Lighter, more reflective surface treatment aggregates have been shown to prevent premature failure of the roadway.

IV. Safety – what effect does light colored aggregate have on streetlight and headlight effectiveness?

Light colored aggregate roadways also improve the effectiveness of streetlights and headlights. Both types of safety lighting depend upon both direct and reflective lighting for their effectiveness. Pedestrians crossing a street at night are illuminated both by the light source, such as a streetlight or headlights, and by light reflected from the street. Pedestrian fatalities are 12% of all motor vehicle deaths. According to the International Commission on Illumination (CIE 1984), "In order to make asphalt pavements lighter, some countries (e.g., Denmark) stipulate the inclusion of a portion of white stones in the bituminous concrete [hot mix asphalt]. In Belgium, the use of light-colored stones for chip…sprinkling…is obligatory on the major roads of the State network." The need for better lighting has become greater because of the aging of the population. "Enhanced visibility due to reflective pavements will help to avoid accidents and reduce the costs of automobile insurance. In addition, better illumination probably reduces auto theft and other street crimes." (Pomerantz, Akbari, & Harvey)

Research suggests that more reflective streets might make it possible to reduce street lighting. The reverse is also true--that non-reflective streets perform poorly and likely increase the need for street lighting. "Changing from surfaces that are 10% reflecting to 30% would result in 20% more light from luminaries reaching a subject in the middle of a street." (Pomerantz, Akbari & Harvey)

Increased roadway reflectivity helps headlights and streetlights to perform better. In a study commissioned by Graniterock, two streets were examined for reflectivity and nighttime pedestrian visibility. The streets were slurry sealed with black aggregate (Mountain View) and grey granite (Cupertino). Dr. Kenneth Ziedman, Ph.D., concluded that the grey aggregate improved streetlight and headlight effectiveness by increasing roadway luminance (brightness) by a factor of two to three times. This substantially increases pedestrian contrast against the roadway background resulting in improved visibility of pedestrians. Dr. Ziedman's paper provides photographs of pedestrians under similar lighting conditions for the two aggregates, which clearly show that the grey aggregate based slurry substantially improves pedestrian visibility.

In addition, Dr. Ziedman debunks the assertion that the higher contrast shown in daytime photographs between roadway striping and the black asphalt surface necessarily results in greater safety. Roadway striping and raised pavement markers (RPMs) are designed with retro-reflective properties, making them plainly visible during darkness over a very wide range of surfaces, from new asphalt pavement to nearly white Portland cement concrete pavement. He also noted that a daytime photograph of pavement markings taken from a standing position is not a valid demonstration of the visibility level of such markings from a driver's viewpoint for either daytime or nighttime conditions.

V. Environmental Benefit – considering pavement reflectivity impacts on heat island effects in urban communities.

Scientists are concerned with a phenomenon called the "heat island effect." This is the tendency of air temperatures to be significantly higher in large cites compared with the surrounding countryside. As cities act as "heat islands," hot weather health hazards are exacerbated, energy demand is increased, and it becomes more difficult to meet air quality goals. One way to reduce the heat island affect is to use pavements with higher reflectivity—i.e., those made with lighter colored aggregates.

The environmental consequences of non-reflective pavement are summarized in the technical article published by Lawrence Berkeley Laboratories and the University of California. (Pomerantz, Akbari, & Harvey) "The dark [pavement] color means that sunlight is not being reflected; the absorbed energy raises the temperature of the pavement and thus the temperature of the air that is near it. This immediately contributes to the heating of the city. When the temperature gets high enough, the modern response is to turn on an air conditioner that further heats the outside air and costs energy. The atmosphere also responds by using the thermal energy to drive the conversion of organic gases and nitrous oxides into smog. There is thus a cost in both energy consumed and degradation of the environment."

The City of Houston has studied how to reduce air temperatures. The *Cool Houston* report concludes that the region should adopt cool paving technologies. "A pavement's cooling attributes result from the color of the binder and/or the aggregate, with a lighter, more reflective material being cooler." The report acknowledges that a focus on pavement reflectivity is a change in priorities. "Solar resistance is not commonly specified in pavement requirements and, as such, this represents a change in paving practices." In Houston, not unlike other urban cities, paved surfaces cover 28% of the land area. Public roadways cover 10% of the ground surface. Making this much area more reflective has environmental benefits.

As noted above newly paved streets are black when they are first paved because the aggregates are coated with black asphalt. However, with the passage of time and vehicle use, the asphalt coating is worn away from the aggregate exposing the constituent aggregate's color. After five years, hot mix reflectivity improves by 15% if a light-colored aggregate is used.

VI. Cost – taxpayers require prudence in local government spending matters.

Some communities have specified the use of black slurry aggregate for aesthetic reasons. "Part of the resistance to light-colored pavement is that it is often associated with being old or worn. Such matters of taste may be modified by education in the practical and aesthetic advantages of lighter colored pavements," reported the University of California and Lawrence Berkeley Laboratories.

Understanding the cost impacts of specifying aggregate from a source that is far from the construction site should speed this new way of thinking about roadway aesthetics. In many cases the largest component of the aggregate cost for slurry seal manufacture is not the cost of the rock, but the cost of transporting the rock from the source to the point of application. Aggregate is most often shipped by truck, and each mile of transit adds to the cost of the slurry seal. There are several sources for light colored aggregate close to the greater San Francisco Bay Area, but no close sources of black aggregate. As this Report is written, there is a sole source of black aggregate slurry seal meeting Caltrans' specifications in California, and that source is located in Tuolumne County. Public works departments that specify black aggregate for slurry seal project unnecessarily increase the cost of the road maintenance program.

VII. The Bottom Line.

Public works departments make an error in not thoroughly educating elected officials of the higher costs (sometimes as much as 19 – 28% in the San Francisco Bay Area) of black aggregate, and the durability, safety and environmental disadvantages of dark colored aggregate readily found in the technical literature. When elected officials are given all of the facts, they have decided to utilize only the Caltrans specification, making no requirement that the aggregate be any particularly color. If color is to be specified, only light-colored aggregate should be used for all of the reasons explained in this Report.

Technical References

"Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas," Leanna Shea Roe, Hashem Akbari, and Haider Taha, Lawrence Berkey National Laboratory, University of California, January 2003. Study identified the "fabric" of urban areas determining that vegetation covers 39% of the land area, roofs cover 21%, and paved surfaces cover 29%.

"Cooler Reflective Pavements Give Benefits Beyond Energy Savings; Durability and Illumination," Melvin Pomerantz and Hashem Akbari, Lawrence Berkeley Laboratory, and John T. Harvey, Institute of Transportation Studies, U. C. Berkeley. Comprehensive overview of roadway research findings regarding benefits of reflective pavements for longer lasting roadways, streetlight requirements, and reduced heat island impacts.

"Cool Houston Plan," Houston Advanced Research Center (HARC), www.harc.edu/coolhouston. Examines changes in public policy that would reduce temperatures in Houston including cool paving technologies recommendations.

"Heat Island Effect: What is the Heat Island Effect?", U. S. Environmental Protection Agency, www.epa.gov. Describes the creation of heat islands and how increased urban temperatures can affect public health, the environment and the amount of energy that consumers use for summertime cooling.

"Human Factors in Traffic Safety," Robert E. Dewar and Paul L. Olson, Lawyers and Judges Publishing Company, 2004. Comprehensive source of information regarding traffic safety matters including fatality statistics, headlight and streetlight design effectiveness.

"Predicting Maximum Pavement Surface Temperature Using Maximum Air Temperature and Hourly Solar Radiation," M. Solaimanian and T. W. Kennedy, Transportation Research Record 1417: 1 – 11, 1993. Compares pavement temperatures with ambient temperatures.

"Preliminary Evaluation of the Lifecycle Costs and Market Barriers of Reflective Pavements," Michael Ting, Jonathan Koomey, and Melvin Pomerantz, Lawrence Berkeley National Laboratory, November 2001. Evaluates the desirability of "topping" hot mix asphalt pavements with reflective materials to reduce long-term road maintenance costs, energy usage and environmental impacts.

"Roadway Reflectivity and Visibility," Dr. Ken Ziedman, Ph.D., November 2005. Provides technical understanding of nighttime pedestrian safety using headlights and streetlights including results of safety study of black aggregate (Mountain View) and grey granite (Cupertino) slurry sealed streets. Grey granite improved roadway luminance (brightness) by a factor of four to six times compared with black aggregate.

Benefits of Cooler Roadways from Light Colored Aggregate

- Cooler pavement temperatures result in a ten-fold reduction in roadway rutting and shoving deformation; these are the significant causes of roadway failure.

- Light colored aggregate results in cooler pavement surface temperatures, slowing the aging effects of sunlight on emulsion and asphalt materials. Emulsion and asphalt provide the "glue" in slurry seals and hot mix asphalts. With aging from higher temperatures, the "glue" becomes brittle or stiff shortening the pavement's life.

- Streetlight and headlight effectiveness is improved when street pavements are more reflective. Improved lighting is likely to reduce pedestrian and vehicle accidents.

- With an aging population, increased lighting is important to an expanding constituent group. Local governments should implement polities now that improve roadway lighting effectiveness.

- Public streets cover a significant portion of the land surface in most cities. In Houston, public streets cover 10% of the land area. Darker colored streets increase pavement temperatures. As street pavement temperatures are increased, outdoor temperatures are also increased due to the transfer of pavement heat into the atmosphere. People respond with air conditioning further raising outdoor temperatures. The result is increased energy usage and cost.

- Higher temperatures in cities result in increased air pollution.