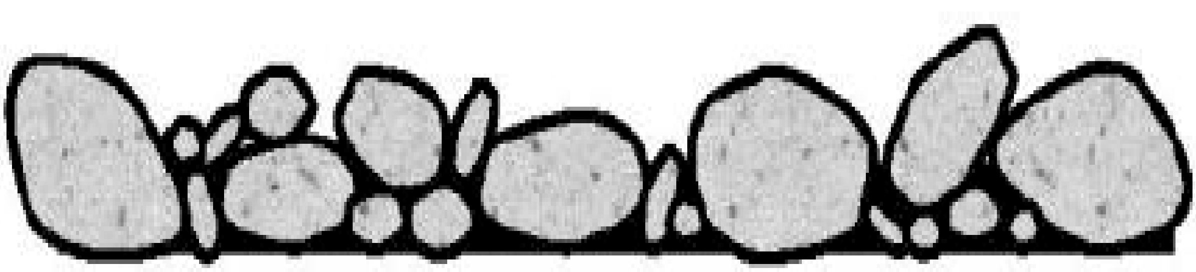
Aggregates for Thin Maintenance Surfaces

Sponsored by the Iowa Highway Research Board
as part of Thin Maintenance Surfaces: Phase Two (TR-435)

Prepared by
the Department of Civil and Construction Engineering
Iowa State University



January 2003

Aggregates for Thin Maintenance Surfaces

Charles T. Jahren
Associate Professor of Civil and Construction Engineering
Iowa State University

Jacob Thorius
Graduate Research Assistant

Department of Civil and Construction Engineering
Iowa State University
394 Town Engineering Building
Ames, Iowa 50011

The contents of this document are taken from the *Thin Maintenance Surfaces: Phase II Report* (TR-435) and are presented here as a stand-alone reference on aggregates for thin maintenance surfaces.

January 2003

Introduction

Important qualities of aggregates used for thin maintenance surface (TMS) include an aggregates wear and skid resistance, shape, gradation, and size. The wear and skid resistance of an aggregate influences the lifetime of the individual aggregate particles, and thus the lifetime of the TMS. A TMS's effectiveness is impacted by the shape, gradation, and size of the aggregate used for the surfacing material along with the lifetime of the aggregate.

Aggregate Types

According to Iowa Department of Transportation (Iowa DOT) Materials Instructional Memorandum T-203, there are six main functional types of aggregate classifications in accordance with their frictional characteristics for bituminous construction:

- **Type 1.** Type 1 aggregates are generally a heterogeneous combination of minerals with coarse-grained microstructure of very hard particles (generally, a Mohs hardness range of 7 to 9) bonded together by a slightly softer matrix. These aggregates are typified by those developed for and used by the grinding wheel industry such as calcinated bauxite (synthetic) and emery (natural). They are not available from Iowa sources. Due to their high cost, these aggregates would be specified only for use in extremely critical situations, such as quartzite, granite, and slags.
- **Type 2.** Natural aggregates in this class are crushed quartzite and granites. The mineral grains in these materials generally have a Mohs hardness range of 5 to 7. Synthetic aggregates in this class include some air-cooled steel furnace slags and others with similar characteristics.
- **Type 3.** Natural aggregates in this class are crushed trap rocks, and/or crushed gravels. The crushed gravels shall not contain more than 60 percent total carbonate (limestone). Synthetic aggregates in this class are the expanded shales with a Los Angeles abrasion loss less than 35 percent.
- **Type 4.** Aggregates crushed from dolomitic or limestone ledges in which 80 percent of the grains are 20 microns or larger. The mineral grains in the approved ledges for this classification generally have a Mohs hardness range of 3 to 4. For natural gravels, the Type 5 carbonate (see below) particles, as a fraction of the total material, shall not exceed the non-carbonate particles by more than 20 percent.
- **Type 4D.** A subgroup of the Type 4 category comprised of those aggregates near, but exceeding, the 20-micron minimal grain size. Type 4D aggregates are not acceptable for use in any asphalt cement concrete surface courses requiring the use of Type 4 or better material.
- **Type 5.** Aggregates crushed from dolomitic or limestone ledges in which 20 percent or more of the grains are 30 microns or smaller.

The aggregate used for a TMS is typically either of Type 2, 3, 4, or 4D friction classification in accordance with the above classes of aggregate. Type 4 and 4D aggregates generally require the use of more binder because they are more absorptive.

The advantages and disadvantages of using quartzite, limestone, or pea gravel as the aggregate for a TMS are listed in Table 1.

Table 1. Advantages and Disadvantages of Aggregate Types

Type	Advantages	Disadvantages
Quartzite	• Particles have sharp edges that provide excellent skid resistance. • High durability. • Pink coloration can be contrasted with other aggregates to delineate portions of the road.	• Binder must be properly formulated to mitigate stripping. • Sharp edges catch snowplow blades, causing wear on blade or plucking improperly bound aggregate from road. • High transportation costs in portions of Iowa that are not close to sources.
Limestone	• Limestones with low clay content are easily and permanently bound by most binders. Higher clay content limestones can be retained by carefully selecting binder. • Sharp edges promote good skid resistances until worn; however, some limestone has excellent durability. • Some limestone has microstructure that promotes good skid resistance by providing rough crystalline faces after worn. • Locally available in many places in Iowa, thus lower transportation costs. • Individual stones may shear apart during snowplowing operations preventing them from being plucked from the road.	• High clay content limestone requires careful binder selection. • Soft limestones will not be durable, loosing sharp edges under traffic. • Individual stones may shear during snowplowing, reducing macro-texture (may not occur in wheel ruts).
Pea gravel	• Round stones provide smoother road surface that may be friendlier to pedestrians, bike riders, skate boarders, and in-line skaters. • Round stones may not catch snowplow blades. • Inexpensive local sources reduce cost.	• Round particles provide less macro-texture for skid resistance. • Round particles provide less stability; this may make them more susceptible to snowplow damage if the blade engages them. • Particles are not from a homogeneous source, so their chemical behavior with binders is less predictable.

Since the construction and monitoring of the test sections in this study, an 11 mile stretch of Pocahontas County Road N28 (between Laurens and Fonda) has been successfully micro-surfaced with the use of limestone from the Martin-Marietta pit in Fort Dodge, Iowa.

Sources of Aggregate

Type 4 crushed aggregates are generally found throughout the state of Iowa (see exceptions in next paragraph), while Type 2 and 3 crushed aggregates are not available in Iowa. However, some Type 2 crushed synthetic aggregate can be obtained in Muscatine County (slag from a steel plant). Most Type 2 and 3 crushed aggregates must be imported from the neighboring states of Minnesota and South Dakota. The raw material Type 3 and 4 crushed gravels can also be found in many portions of Iowa; however, they are rarely produced.

Figures 1 and 2 are maps of the state of Iowa that show the approved locations for aggregate and crushed stone, respectively, to be used in TMS (maps from Iowa DOT). Most of the approved aggregate and crushed stone is located in eastern Iowa, particularly in the northern half, within two or three counties of the Mississippi River. Every county in Iowa either has an approved aggregate source or there is one located within a neighboring county. However, this does not hold true for those counties in the northwest portion of the state. In this part of the state there are very few approved sources, but most of the aggregate can be easily shipped from the Sioux City, South Dakota area.

Aggregate Wear Resistance

Of the aggregates typically used for a TMS, Type 2 aggregates are the hardest and can withstand the wear of snowplow blades and traffic better than Type 3, 4, or 4D aggregates. However, as experienced by our test sections, Type 2 aggregates may be dislodged easier because a snowplow blade may catch their sharp corners and edges easier and pluck them from the binder if they are not well bound. The aggregates that are crushed down to a smaller size from the initial parent aggregate tend to be angular so particles interlock with each other better. Therefore, they are better able to withstand the starting, stopping, and turning forces from vehicles on the roadway.

Aggregate Skid Resistance

The skid resistance on a road surface comes from the macro- and micro-texture of the aggregate that is spread on the road. Macro-texture is the large-scale texture on the road surface caused by the size and shape of the aggregate in the asphalt binder. Micro-texture is the small-scale texture of the individual aggregate chips caused by the hard mineral grains distributed through the softer mineral material of the aggregate chips.

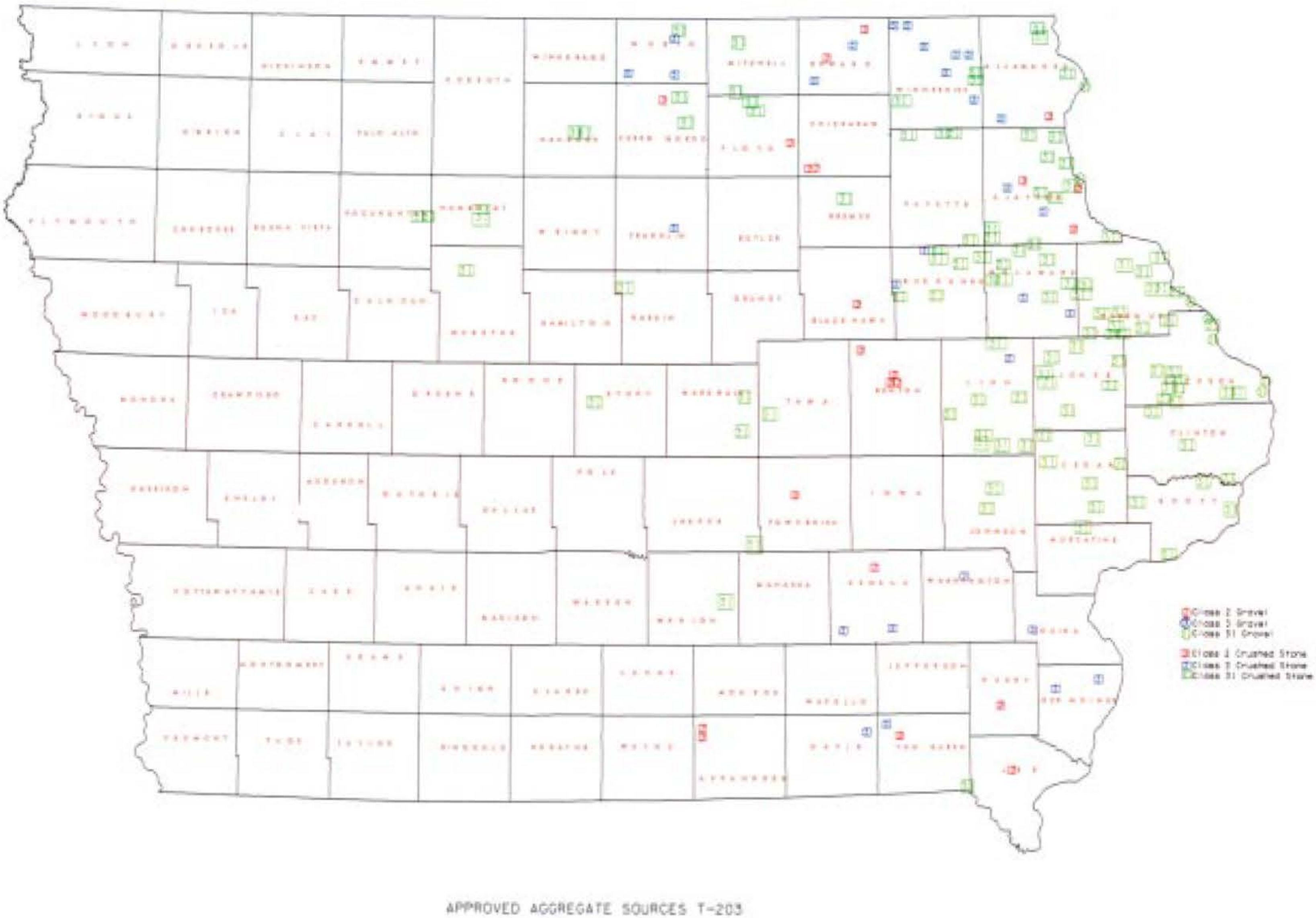


Figure 1. Aggregate Locations in Iowa Approved for Use in Thin Maintenance Surfaces

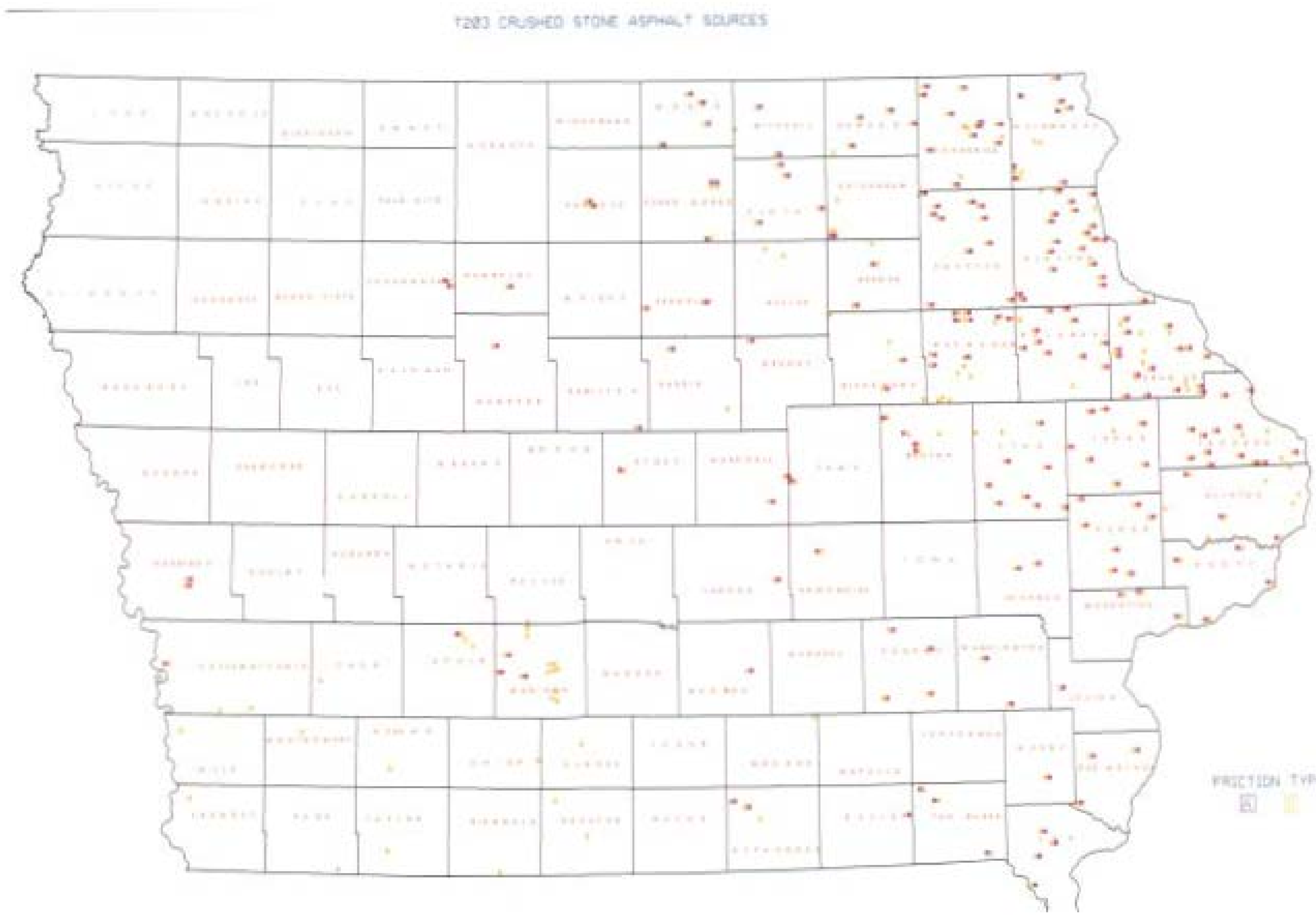


Figure 2. Crushed Stone Locations in Iowa Approved for Use in Thin Maintenance Surfaces

- Aggregates that are composed of a combination of hard and soft minerals seem to have a higher skid resistance than aggregates composed of minerals of relatively the same hardness[1]. The idea behind this is that the soft mineral grains wear away first, exposing the hard grains, which provides the increased skid resistance. These particles and the matrix holding them together are then worn down exposing fresh unpolished particles, thus allowing the process to repeat itself.
- Aggregates that contain larger and more angular mineral grains or crystals in the individual aggregate chips are expected to have a higher skid resistance[1].
- The more uniform distribution of these coarser and harder mineral grains throughout the softer minerals, the higher the expected skid resistance.
- The variations of frictional resistance along roadway surfaces are deemed to be from short- and long-term seasonal changes[2]: Long dry periods tend to allow for the aggregate to be polished more. Long wet periods tend to allow for the aggregate to be rejuvenated by exposing fresh, angular crystals.
- Freeze-thaw cycles seem to create a rejuvenating effect on the micro-texture of the aggregate chips, which is caused by the softer particles coming off the surface leaving the harder particles exposed. This leads to an increase in skid resistance.
- Soft materials that wear easily may have high skid resistance before they wear below the level of the binder for reasons stated above.

Aggregate Shapes

The shape of aggregate used in TMS is considered to be either flat, cubical, or round.

Flat Aggregate

- The flatter the aggregate, the more susceptible it will be to change in orientation from the impacts of traffic. Aggregate chips that are flat and in the wheel paths are caused, from the tire loads, to lie on their flattest side. This causes a thinner TMS and a chance for increased bleeding if the binder is too thick in the wheel paths or loss of aggregate in the non–wheel paths if the binder is applied to thin. This is more of a problem for seal coats; however, a hot mix is also weakened by the use of flat aggregates. Figure 3 shows how the flat aggregate chips are re-oriented in the wheel paths of traffic.
- For parking lots and roadways with very low volumes of traffic, such as residential streets, the use of flat aggregate chips may not create a problem. This is because there may not be enough traffic or the traffic may not be confined to specific wheel paths, as experienced on a road with higher traffic counts, to cause the aggregate chips to be re-orientated.

[1] Abdul-Malak, M. A., Meyer, A. H., and Fowler, D. W. 1989. Research Program for Predicting the Frictional Characteristics of Seal-Coat Pavement Surfaces. *Transportation Research Record 1217*, 53-64.
[2] Abdul-Malak, M. A., Meyer, A. H., and Fowler, D. W. 1993. Major Factors Explaining Performance Variability of Seal Coat Pavement Rehabilitation Overlays. *Transportation Research Record 1388*, 140-149.

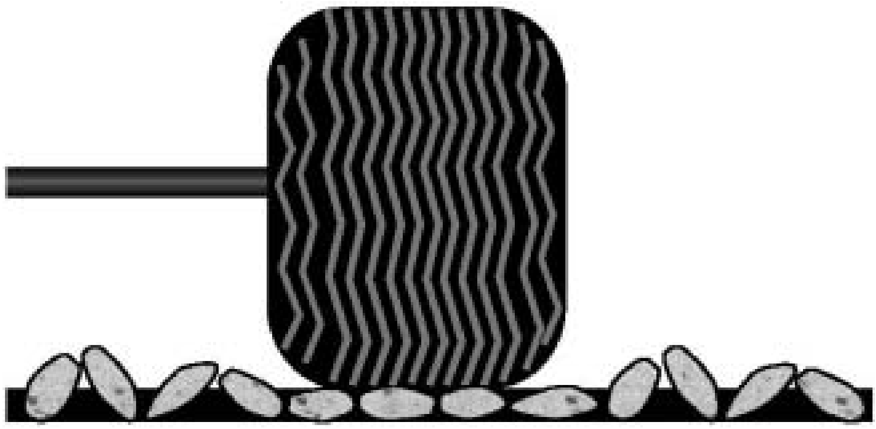


Figure 3. Flat Aggregate Chips Being Re-oriented Under Traffic in the Wheel Path[3]

Cubical Aggregate

- As a result of cubical chips all being relatively uniform in shape, traffic will not reorient the chips. Since the chips are uniform in shape, whichever way they are orientated the TMS will have relatively the same thickness, even in the wheel tracks. Figure 4 shows how cubical aggregate chips withstand traffic forces better than flat chips.
- Because of their angular edges, cubical aggregate chips interlock together, creating a surface that is more resistant to the pounding of traffic and snowplow blades.
- They are also better able to withstand the starting, stopping, and turning actions of vehicles as they travel the roadway.

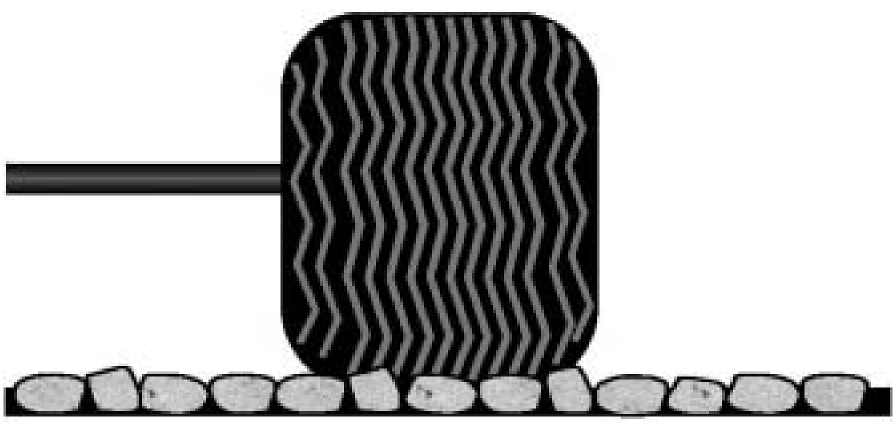


Figure 4. Cubical Aggregate Experiences Little Effect in Orientation from Traffic[3]

[3] Janisch, D. W., and Gaillard, F. S. 1998. *Minnesota Seal Coat Handbook*. Minnesota Local Road Research Board Report MN/RC – 1999-07. St. Paul, MN: Minnesota Department of Transportation.

Round Aggregate

- The rounder the aggregate, the more susceptible it will be to rolling and displacement under stopping and turning actions of traffic. Because of this, round aggregates should not be used on high volume roadways where many turning, starting, and stopping forces may be experienced.
- Round aggregates are susceptible to being dislodged under snowplow blades because they do no interlock with each other as well. However, because of the aggregate's roundness, the blade does not catch them as easily as aggregate with jagged edges. The authors found anecdotal evidence that round aggregate withstood snowplowing well in residential areas.
- The use of graded round aggregate allows for the chips to lock more readily with each other. The smaller chips are able to fill the voids between the larger chips, thus locking them together.
- Round aggregates tend to create a smoother surface, especially when used in a double seal fashion. This provides a surface that is more comfortable to walk on, especially in parking lots and places where people may fall down and skin their knees.

Table 2 lists the advantages and disadvantages of using different shaped aggregates in a TMS.

Table 2. Advantages and Disadvantages of Aggregate Shapes

Shape	Advantages	Disadvantages
Cubical	• Greater stability in wheel tracks and areas where traffic is turning. • Allows higher shot rate for binder, ensuring that aggregate particles are better attached.	• Requires more expensive production techniques, which raise cost and limit availability, and in some cases increases volume of waste products in quarry.
Flat	• May be more easily produced and therefore lower in cost in some areas.	• Flat particles reorient under traffic to lowest possible elevation, possibly submerging in binder and causing tracking and bleeding. • Reduces design shot rate, which may cause some particles to be less firmly bound.
Round	• Create a smoother surface that is more comfortable to walk on. • Do not catch the blade of a snowplow because of roundness.	• More susceptible to rolling and displacement under starting, stopping, and turning actions of traffic. • Do not interlock with each other as well, unless a graded aggregate is used, thus dislodged easier by snowplow blades.

Aggregate Gradation

Aggregates used in TMS are either of roughly one size or of multiple sizes—this is, a graded aggregate.

One-Size Aggregate

- Aggregate is considered one-size if nearly all the aggregate is retained on two consecutive sieves. When one size aggregate is used, an individual aggregate chip does not stick up higher than others around it, so no individual chip can be dislodged easier from a snowplow blade. Figure 5 shows a cross section of one-size aggregate on a roadway surface (from Janisch and Gaillard, *Minnesota Seal Coat Handbook*, 1998). Note that all particles are fairly close to the same size and no one particle is easier to dislodge than the others. This is an idealized artist's rendition; actual aggregate pieces will probably have sharp corners and edges. Actual cross sections would likely show more angular particles, some of which stand taller than those shown in the drawing.
- Because the aggregate chips are of one-size, there is a greater contact area between the tires and the road surface.
- As a result of the channels between the aggregate chips on the surface, there is increased drainage of water, which also increases the effective frictional value of the wet road surface by reducing the tendency to hydroplane.

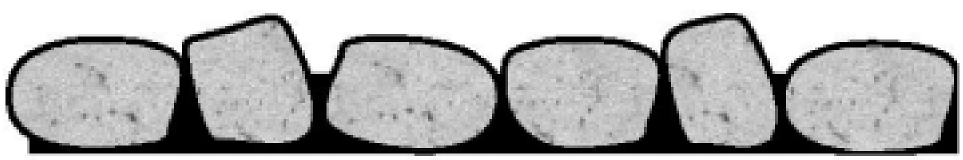


Figure 5. Cross Section of One-Size Aggregate in a Thin Maintenance Surface

The US 69 test sections included one test section with one-sized quartzite aggregate, which suffered considerable snowplow damage, possibly due to angular particles that caught the snowplow blade.

Graded Aggregate

- Generally it is thought that the more graded an aggregate, the less desirable it is, because there is less room for the binder to fit between the chips. The use of graded aggregate reduces the tolerance regarding the amount of binder used. Thus, usually bleeding occurs because of too much binder being used, or there is loss of aggregate because not enough binder was used. Figure 6 (from Janisch and Gaillard, *Minnesota Seal Coat Handbook*, 1998) shows a cross section of graded aggregate on a roadway surface.
- Some aggregate chips protrude farther above than many others, making them easier to dislodge under traffic and snowplow blades.
- Portions of the aggregate chips may become completely imbedded in the binder, resulting in an increased opportunity for bleeding to occur on the road surface.
- There is a greater chance for more dust to be present with the use of graded unwashed aggregate, causing the binder to not stick to the aggregate as well and loss of aggregate to occur.

- Graded aggregates tend to produce a tighter bound surface. This tighter bound surface leads to a quieter ride for the vehicle occupants traveling over the road surface.
- The use of graded aggregate creates less contact surface area between the tire and road because of different sized aggregate particles protruding up farther than others.

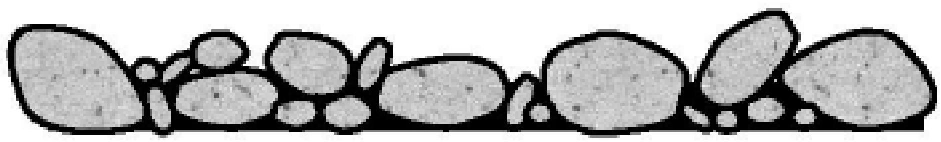


Figure 6. Cross Section of Graded Aggregate in a Thin Maintenance Surface

Despite the difficulties mentioned with graded aggregate, several test sections constructed under this project with graded aggregate exhibited excellent performance. The advantages and disadvantages of using either one-size or graded aggregate for a TMS are listed in Table 3.

Dusty Aggregate

The amount of dust in the aggregates used for a TMS should be kept to a minimal amount. CRS emulsions should not be used with dusty aggregates, while high float emulsions work with small dust amounts and cutback emulsions work better with dusty aggregate. More on the types of emulsions and dusty aggregate will be discussed later. The presence of dust on the cover aggregate prevents good adhesion between the aggregate and the applied binder, resulting in a loss of aggregate chips when the roadway is subjected to traffic. For CRS emulsions, a rule of thumb is that if you pick up a hand full of aggregate and throw it down and notice dust on your hand, it is too dusty.

Table 3. Advantages and Disadvantages to Using Either One-Size or Graded Aggregate

Gradation	Advantages	Disadvantages
One-size	• More void space (compared to graded aggregate) for more binder to be shot and allows more tolerance with regard to binder application rate. • Allows spreading of aggregate in one layer so each particle is bound to the road surface, not other aggregate particles. • Mitigates tracking by keeping tires away from binder. • Theoretically prevents snowplow blades from catching single aggregate particles that stand above others and plucking them out. • Requires lower application rate by weight per square area compared to graded aggregate.	• Road may seem rough or noisy to occupants (though no worse than any other road with an open texture). • May add to cost of aggregate if fine material becomes a waste product, which cannot be used in another product. • May not be produced in certain geographic areas, thus requiring long distance transportation and more expense. • Some aggregate may be plucked or sheared off by snowplow blade because sharp corners may stand above other aggregate pieces.
Graded	• Provides a smoother, tighter road surface. • Uses fine material from quarry that may otherwise become a waste product. • High availability locally in Iowa, thus low transportation costs.	• Reduces macro-texture, thus increasing risk of hydroplaning. • Lack of void space allows less binder to be shot and less tolerance in binder shot rate, compared to one-size aggregate. • Subject to tracking because some aggregate may be submerged in binder. • Subject to aggregate loss because some aggregate is not bound directly to the road surface. • Requires higher application rate in weight per square area when compared to one-size aggregate.

Aggregate Size

The size of aggregate used in a TMS falls in one of two categories: small aggregate (<=3/8”) or large aggregate (>3/8”).

Small Aggregate

- The design shot rate is smaller when smaller aggregate is used. This is because it takes less binder to bind the aggregate particles to the roadway. As a result of a smaller shot rate, there is a lower cost.
- Because design shot rate is smaller, there is less binder available to seal the cracks and there is less room for error in the binder application rate. If too much binder is used, flushing occurs, and if too little binder is used, the aggregate particles will not stay bound to the roadway.

- A smoother tighter road surfaced is created with the use of smaller aggregate, but this leads to less macro-texture on the road surface.
- A smaller weight per square area of aggregate to be spread is required.
- If the aggregate is picked up by the tires, often called fly rock, less damage is done to vehicles with the use of a small aggregate.

Large Aggregate

- The design shot rate is larger with the use of large aggregate. Thus, there is more binder available to seal the cracks. Also, there is more room for error in the binder application rate. However, the higher design shot rate leads to higher costs.
- Larger aggregate is less likely to wear to the point where the tires and binder would be in contact with each other.
- There is more macro-texture, increased skid resistance, with large aggregate. However, this greater macro-texture leads to more road noise.
- A larger weight of aggregate per square area to be spread is required.
- If the large aggregate becomes dislodged and picked up by the tires, there is a greater chance of damage to the vehicles.

The advantages and disadvantages of aggregate sizes used in TMS are listed in Table 4.

Table 4. Advantages and Disadvantages of Aggregate Sizes

Size	Advantages	Disadvantages
Small (<=3/8”)	• Provides a smoother, tighter road surface. • Requires a smaller weight per square area of aggregate to be spread. • Fly rock does less damage to vehicles. • Design shot rate is smaller, thus lower cost.	• There is less room for error in the binder application rate (the distance from the top of the aggregate to the top of the binder is smaller). • Design shot rate is smaller, thus less binder available to seal cracks. • The top of the aggregate may wear down more quickly allowing tire contact with the binder. • Less macro-texture.
Large (>3/8”)	• Less sensitive to errors in binder application rate. • Design shot rate is larger; more binder available to seal cracks • Aggregate is less likely to wear sufficiently to allow tires to contact the binder. • More macro-texture.	• Like other open surfaces with high macro-texture, more road noise for vehicle occupants. • Larger weight of aggregate per square area to be spread. • Fly rock is heavier and more likely to damage vehicle. • Design shot rate is higher, thus higher cost.