Chip Seals
Examination of design and construction in two countries

Indridi Thor Einarsson

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Indridi Thor Einarsson

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Committee members:

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Joe P. Mahoney

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G. Scott Rutherford

Date:_________________________

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University of Washington

Abstract

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Indridi Thor Einarsson

Chair of the Supervisory Committee:
Professor Joe P. Mahoney
Civil and Environmental Engineering

Co-chair of the Supervisory Committee:
Professor G. Scott Rutherford
Civil and Environmental Engineering

Bituminous surface treatments or chip sealing is a commonly used method worldwide for paving a roadway. A chip seal consists of a layer of asphalt binder that is overlaid by a layer of aggregate embedded in the binder. It provides protection to the existing surface layer from tire damage and a skid resistance surface texture for vehicles. Chip sealing is considered a low cost alternative compared to other pavement surfaces and since many transportation agencies have tight budgets, its use is likely to increase in the future.

The Washington State Department of Transportation, WSDOT, and the Icelandic Road Administration, ICERA, manage a similar amount of chip sealed roads in lane kilometers. The focus of this paper is on reviewing and comparing the two regions in the following categories regarding chip seals:

- Materials; binder and aggregate
- Standard specifications
- Construction practices

An introduction to chip sealing is presented as well as two design methods used for estimating application rates of binder and aggregates, McLeod design method and Australian design method. Four chip sealing case studies, two from each region, are reviewed and their designs compared to the design methods.

Both regions are abundant with quality aggregate resources but gradation types are different since slightly larger and more uniformly graded aggregates are used in Iceland. Rapeseed oil is added to the asphalt in Iceland while emulsions are used in Washington.

Standard specifications differ considerably between the regions. WSDOT standards are more detailed and more to date than the Icelandic standards which haven't been updated since 1995 and do not address some key components of today's chip seals in Iceland.

Application rates are empirical in both regions and primarily based on experience rather than engineering science.

The case studies revealed substantial differences in the construction process of a chip seal project between Iceland and Washington. Inspection level is very high at WSDOT while ICERA performs minimal inspection. Some imperfections of the methods of work were identified on all projects, some of which were reflected on the finished surface. Icelandic case study projects were more expensive, in dollars per square meter, than the Washington projects.

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1 Introduction

Bituminous Surface Treatment, BST, is a common roadway surface treatment used worldwide. It is used for two main purposes; as a new construction wearing course and as a preventive maintenance for an existing pavement. This paper will focus on chip sealing as a preventive maintenance procedure in Washington State and Iceland. BST, or chip seal, consists of a layer of asphalt binder that is overlaid by a layer of aggregate embedded in the binder that furnishes, among other things, protection to the existing surface layer from tire damage and a skid resistance surface texture for vehicles (Gransberg & James, 2005). Chip sealing is a low cost alternative compared to other pavement surfaces but the roadway has to be resurfaced more frequently because a severely distressed underlying surface will decrease the quality of the chip seal and shorten its service life (Gransberg & James, 2005).

Chip Sealing is at first glance a simple procedure and a straightforward method of paving a roadway. Reviewing available research and literature on the subject reveals that there is a lot more to it. Although some agencies base their chip seal design standards and construction merely on experience, others have developed more detailed standards and base their design on engineering principles. It is a common opinion that design and installation of chip seals involves a significant degree of “art”. A lack of solid design methods often incurs trial and error installations of chip seals where the design is changed during the construction. Therefore it is important that agencies that haven’t already done so start aim at “removing the art from the chip seal process and replacing it with solid engineering science“ (Gransberg & James, 2005).

In the US state of Washington, 29,000 lane km are paved with either hot mix asphalt (HMA), portland cement concrete (PCC), or chip seals. Washington State Department of Transportation, WSDOT, manages 7,800 lane km of BST’s which accounts for 27% of WSDOT’s lane km (Uhlmeyer, 2008).

The Icelandic Road Administration, ICERA, manages Iceland’s rural roadway network, a total of 26,000 lane km of which about 8,280 are paved with BST’s. The vast majority of ICERA´s flexible pavements are BST’s, see Table 1.

The agencies manage roadway networks of similar total length although the composition of the roads is different. Length km of chip sealed roads is similar with Iceland exceeding Washington State by 500 km.

Table 1 - Lane miles managed by WSDOT and ICERA, source WSDOT and ICERA.

	WSDOT		ICERA	
Type of Pavement	**Lane-km**	**% of Total**	**Lane-km**	**% of Total**
HMA	17,279	60%	788	3%
BST	7,765	27%	8,279	32%
PCC	3,627	13%	4	0%
Gravel roads	N/A	0%	17,024	65%
Totals	**28,671**		**26,096**	

Service life of a chip seal pavement has proven to be similar in Washington State and Iceland, between 5-10 years in general, meaning that chip seal pavements have to be resealed every 5-10 years. In Australia, New Zealand, United Kingdom, and South Africa, the average chip seal service life is 9.6 years (Gransberg & James, 2005). Construction methods are somewhat different between the two regions; Iceland uses larger aggregate sizes and a different kind of binder than is normally used in Washington State. Icelandic climate resembles Washington's, especially eastern Washington's climate which has significant freeze and thaw effects. Another mutual factor between Iceland and eastern Washington is the abuse by snow plows and studded tires during the winter which has a significant impact on the pavements.

This study will focus on the comparison between Washington state and Iceland in the following categories;

- Materials
- Standard specifications
- Contracting
- Construction practices

The fundamental question that will be attempted to answer is: *is there something Icelanders can learn from Washington State and vice versa*?

Four case studies will be presented, two from Eastern Washington and two from Iceland. Construction techniques will be compared and binder and aggregate application rates will be compared to the McLeod design method and the Australian design method.

2 Chip seals

Chip seals have been used from the 1920’s in the US when they were used as a surface for low volume gravel roads (Gransberg & James, 2005). Since then it has been used successfully both as a new pavement method and as a preventive maintenance treatment for existing pavements. In Iceland, chip sealing was first used in 1978 when a 15 km section was paved in southern Iceland. Chip seals are mostly used on low volume roadways with ADT<5,000 although some countries like South Africa and Australia use it on higher volume roads with ADT up to 50,000 (Gransberg & James, 2005). The main reason most agencies have a limit on traffic volume for chip seals is because of traffic control. If speed can be limited for sufficient amount of time, there are no limits on traffic volume (Janisch & Gaillard, 1998).

A chip seal consists of a layer of asphalt binder that is covered with a layer of aggregate. It is most commonly applied on top of an existing pavement to protect it from tire damage, to prevent water penetrating through it, and to shield it from the sun. Chip sealing also gives the roadway a macrotexture that increases skid resistance of the surface. The underlying pavement has to be in fair or good condition for the chip sealing to work effectively. Large cracks or excessive distress in the existing pavement will decrease the service life of the chip seal. If existing pavement is in poor condition with potholes, deep wheelpath rutting or large cracks, it must be repaired before applying the chip seal. Chip sealing is merely a surface treatment and does not add to the structural capacity of the roadway.

Multiple types of asphalt binders can be used in chip sealing. The binder acts as a coating on the existing pavement and holds the aggregate that is applied on top of it to the roadway. Selection of a suitable binder for a specific project is based on the type of aggregate used, condition of existing pavement and expected weather during and following construction. The two most common binder types used for chip seal operations are cutback asphalt binders and emulsion binders.

2.1 Cutback Asphalt Cement Binders

Before the use of emulsified binders became standard practice in the US and other countries, asphalt cement or cutback asphalt binders were used for chip sealing. Cutback asphalt consists of about 85% asphalt cement and 15% cutter or solvent, by weight. The amount of the cutter predicts the viscosity of the asphalt, the more cutter, the lower the viscosity which means more fluid asphalt (Asphalt Seal Coats, 2003). Typical solvents include naphtha (gasoline) and kerosene (Janisch & Gaillard, 1998). Using naphtha means the asphalt will be rapid curing but kerosene is medium curing. Because of its high viscosity at ambient temperature, it needs to be applied at a temperature of 150^{o}C – 175^{o}C. The use of cutback asphalts has rapidly declined due to the hot application temperature and volatile constituents that evaporate and pollute the atmosphere. Petroleum solvents used in the cutback asphalts are expensive and require higher amount of energy to produce compared to water and emulsifying agents used in emulsified asphalts (Cutback Asphalt, 2007).

2.2 Emulsion Binders

Emulsion binders consist of asphalt globules suspended in water. Because water and asphalt are two incompatible components, a chemical solution (emulsifier) is needed to disperse those components and make the asphalt soluble in water (Janisch & Gaillard, 1998). Emulsifiers can be produced with anionic or cationic charges. As opposite charged particles attract, emulsified asphalt should have an opposite charge of that of the aggregate used. Emulsions are also categorized based on their curing times or how long it takes the water to evaporate from the emulsion and revert back to pure asphalt. Those categories are; Rapid Setting, Medium Setting and Slow Setting. High float emulsions are also available that will increase the thickness of the asphalt film on the aggregate. High float emulsions are often used with dusty aggregates that won't have sufficient adhesion with typical emulsion binders. Emulsions are applied at a temperature 52-85^{o}C, much lower temperature than cutbacks which means less energy consumption for heating as well as it reduces the risk of burning accidents. They are less sensitive to climatic factors like cold weather and light rain compared to cutbacks (Gransberg & James, 2005). Emulsions contain no volatile constituents that evaporate into the atmosphere and cause pollution. On the other hand, more binder is needed due to lower residual asphalt rate which means increased hauling cost to the project sites.

2.3 Biodiesel binders

Although not very common, biodiesel binders have been used in a number of countries like Iceland, Denmark and Austria, where they originated (Hjartarson, 2009). These binders use biodiesel or rapeseed oil as the bonding agent in the asphalt and it is usually added in the amount of 5-10% of weight. In Austria, rapeseed oil has also been used in asphalt emulsions. This type of binder is fairly new to the industry and experience has yet to be gathered to evaluate its performance. It does have some advantages over cutback and emulsion binders. The rapeseed oil is a permanent component of the binder which means no evaporation occurs from it after application. The amount of binder applied is therefore reduced by 10-20% or 30-40% compared to cutbacks or emulsions, respectively. Application temperature of biodiesel binders is similar to cutback binders, 145-160^{o}C.

2.4 Aggregate

Aggregate type used on a specific project is in most cases determined by the availability of aggregates in the vicinity of the project. However, in New Zealand and Australia, aggregates are transported up to 800 km if quality aggregates are not available locally, which demonstrates the essential role of the aggregate in a chip seal performance. Aggregate type has a critical role in the selection of binder and dictates the construction method for chip sealing (Gransberg & James, 2005).

Aggregates can be categorized as natural and synthetic aggregates. Synthetic aggregates are uncommon and are only used where natural aggregates are not available and the cost of transporting them to the project site is too high. Examples of synthetic aggregates are lightweight aggregates made of expanded shale, clay or slate. Due to its light weight it could be considered for use in areas where windshield damage is a major concern (TxDOT, 2004).

Natural aggregates can be categorized as three types; crushed gravel, crushed stone and natural gravel.

Experience has shown that uniformly graded aggregate will result in the best performance. Uniformly graded aggregate will ensure even embedment of all particles as described in Figure 1. Aggregate particle sizes vary, but the most commonly used aggregate sizes are between 8 and 16mm in diameter for a single layer chip seal. If a two layer chip seal is being used, the second layer is usually about half the size of the first layer (Janisch &

Gaillard, 1998). The quality of the aggregate is dependent to factors such as cleanliness, shape, toughness and soundness, and porosity. Those factors will be discussed in the following paragraphs.

2.4.1 Cleanliness

Dirty or dusty aggregates are less susceptible to adhesion to the asphalt which can cause excessive loss of aggregate. In most standard specifications, the amount of fine particles passing the 0.075 mm (No 200) sieve is limited to 1-2%. If the amount of fines exceeds that limit, the aggregate should be screened or washed with water before it's applied on the roadway. Another option is to use high float emulsions which can be used with aggregates having up to 5% passing the 0.075 mm (No. 200) sieve (Janisch & Gaillard, 1998).

2.4.2 Shape

Cubical shape aggregate particles have proved to have the best performance. Cubical particles will have better interlock between the particles because traffic does not have a major impact on the orientation of the particles (Janisch & Gaillard, 1998). As a result asphalt flushing is less likely to occur because gaps between the particles are evenly distributed. Flat and elongated particles will however tend to end up on the flat side, especially in the wheelpaths, causing flushing or bleeding of the asphalt binder, see Figure 1.

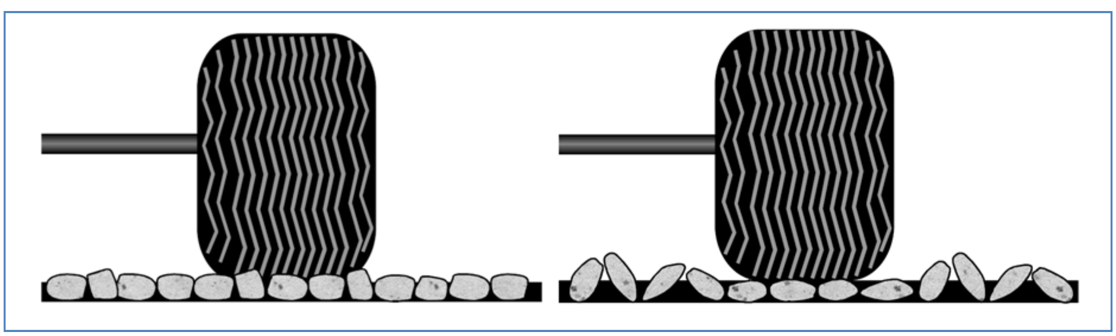

Figure 1 - Difference between cubic and flat and elongated aggregates. Source; Minnesota Seal Coat Handbook

Angularity of the aggregate is another important component in chip seal performance. Round aggregates are more susceptible to displacement by traffic movements because they have less interlock than angular aggregates (Gransberg & James, 2005). Most agencies require that a specific percentage of particles need to have at least one fractured face to ensure interlock between them.

2.4.3 Toughness and soundness

Toughness and soundness are based on resistance to abrasion, degradation, and polishing (Gransberg & James, 2005). Poor aggregates can wear down do to traffic, especially studded tires, freeze thaw cycles and snow plowing. Quality aggregate with good resistance to those strains will increase the service life of the chip seal.

2.4.4 Porosity

Although not a common problem, severely porous aggregate will absorb some of the binder which can result in aggregate loss due to lack of binder for retaining the aggregate on the roadway surface. Modified binders or precoating the aggregate are methods that can be used to mitigate the impact of porous aggregate (SANRAL, 2007).

3 Construction Equipment

Construction equipment for chip sealing consists of;

- Asphalt hauling tank
- Asphalt binder distributor
- Chip spreader
- Hauling trucks
- Rollers
- Sweepers
- Hand tools

3.1 Asphalt hauling tank

The asphalt hauling tank transports the asphalt binder from the production plant of the binder or storage tanks to the project site. The tank is insulated to keep the binder at desired temperature. When on the jobsite the hauling tank fills up the binder distributor, see Figure 2.

Figure 2 - Asphalt hauling tank filling up a binder distributor tank.

3.2 Asphalt binder distributor

Asphalt binder distributor sprays the asphalt over the existing surface of the roadway just before the chips are spread. The distributor has an insulated tank for storing asphalt equipped with heating system and circulation pump that keeps the asphalt in consistent uniform heat according to specifications and spraying operations. A spray bar is situated at the rear end of the tank. The spray bar has nozzles that distribute the asphalt on the roadway surface. A typical spray bar is 3.7 m wide although they can be up to 7.3 m wide in some cases. The types of nozzles used depend on the desired application rate and the type of asphalt used. Spacing between nozzles is usually either 4 or 6 inches and installed at an angle to the spray bar between 15 and 30 degrees as shown in Figure 3. It is very important that all nozzles are at the same angle to the spray bar to ensure even distribution.

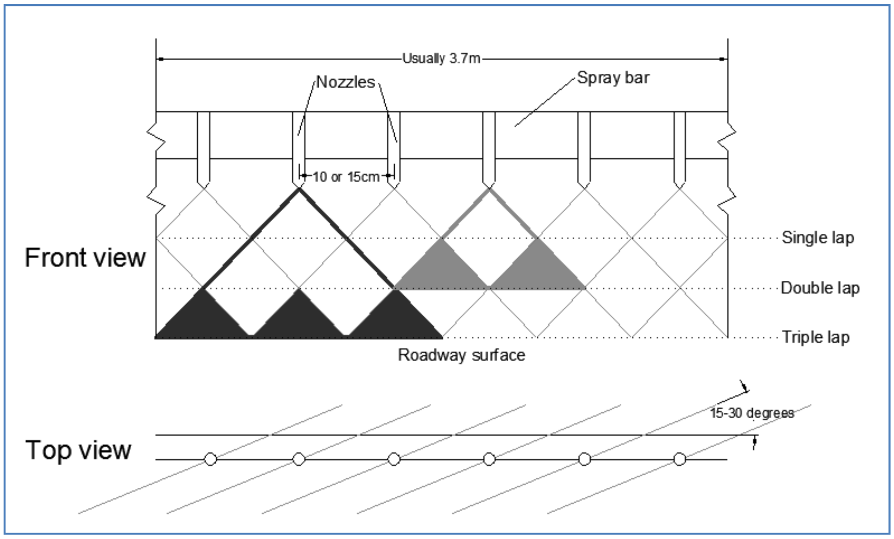

Figure 3 - Spray bar coverage and nozzle alignment

The distributor is also equipped with measuring devices and gauges for measuring pressure, application rate and heat of the asphalt. New distributors have a computerized system that controls the application rate of each nozzle and allows the operator to adjust the rate of application and the spray bar width and height without stopping (Gransberg & James, 2005). Most agencies require a computerized distributor in their specifications.

Figure 4 - asphalt binder distributor

3.3 Chip spreader

Chip spreaders can be divided into two classes; dump truck box chip spreaders and self propelled aggregate spreaders. Dump truck box spreaders are mounted on to the back end of a conventional dump truck as seen in Figure 5. These kinds of spreaders are mainly used in smaller jobs or in maintenance work like patching.

Figure 5 - dump truck box chip spreader.

Source: http://imgs.tootoo.com

Most agencies specify the use of self propelled chip spreaders in their standard specifications, see Figure 6. They are equipped with a receiving hopper in the rear, where dump trucks load the aggregate into. The truck is hooked to the spreader which drags it until it’s empty. A belt conveyor carries the aggregate to the spreading hopper and a discharge roller that assists in ensuring an even spread of the aggregate to the discharge gates. Newer spreaders are computer controlled that allows the operator to control spreading rates of individual discharge gates and adjust the width of the spreader without stopping. The most advanced spreaders are also equipped with hydraulic automatic gate controls that adjust the gate openings according to the speed of the spreader, ensuring application rates are as specified (Gransberg & James, 2005).

Figure 6 - Self propelled chip spreader

3.4 Rollers

Rolling is to some considered the most overlooked component of the chip sealing process, although it has a major impact on the performance and service life of the project. Rolling in a chip seal project serves a different purpose than rolling of HMA, it is not to compact the material under the roller but to initiate the orientation of the chips so that maximum bonding can occur and to work the binder in between the voids of the aggregate (SANRAL, 2007). The traffic on the roadway following construction then finishes the orientation process. Due to this purpose of the rolling, pneumatic tire rollers are by far the most used rollers in chip seal process. Other rollers used occasionally are steel-wheeled rollers and rubber coated steel wheeled rollers.

Pneumatic tire rollers are self propelled and most of them have 4 wheels on the front axle and 5 on the back axle, all of which are pneumatic. The setup of the tires is such that the rear tires roll the gaps that are in between the front tires. The rollers are 150 to 200 cm in width and can weigh from 4-16 metric tons.

Use of steel wheeled rollers is less desirable then pneumatic ones because the steel drum bridges over any depressions in the road such as wheelpaths and therefore fails to properly orient the aggregates. Steel wheeled rollers must never be used on vibration because it can damage or degrade the aggregate (Gransberg & James, 2005).

Figure 7 - Pneumatic tire rollers

3.5 Sweepers

Sweeping is often the first and last component of a chip seal job. The existing roadway surface has to be swept prior to applying the binder and aggregate to acquire a clean surface free of debris and foreign matter. When the aggregate has been applied and rolling has finished, the road has to be swept to remove excess loose aggregate that remains on the roadway. Sweeping is done from several hours after construction to several days, depending on the curing time of the binder and traffic volume. There are three types of sweeping equipment; rotary brooms, pickup sweepers and vacuum sweepers. Rotary brooms will sweep the excess aggregate chips to the side/shoulder of the roadway without removing it. These brooms are the most common ones to use in rural areas. Pickup sweepers are used in urban areas where excess aggregate cannot be swept to the shoulders. They sweep the chips to a suction head that deposits the material in a storage tank. Pressure of the bristles should be kept to a minimum so that they won't dislodge the aggregate from the binder. Bristles made of plastic are preferred over steel bristles as they are less likely to damage the chip seal. Vacuum sweepers remove the aggregate through suction without any sweeping. Using a vacuum sweeper minimizes the damage on the newly constructed chip seal.

3.6 Hand tools

Various hand tools are commonly used on a chip sealing project, including; brooms, shovels and squeegees. Those tools are usually stored on the rollers for the operators to use to fix specific spots, for example where aggregate cover is not sufficient.

Figure 8 - Roller operator covering a bleeding wheelpath before rolling

4 Materials used in the two regions

In the following chapter, binders and aggregates used in Iceland and Washington State will be discussed and compared.

4.1 Aggregate in Iceland

Iceland is a sparsely populated country, with a population of about 300,000 and a surface area of 103,000km^2, a little more than half the size of Washington State. In Iceland, the most common petrographic type of aggregates used in roadway construction is basalt, mostly consisting of fresh basalt, transformed basalt or basalt glass (Helgason, Marteinsdóttir, Sveinsdóttir, & Magnúsdóttir, 2006). Aggregates are produced mainly from two different sources; rock quarries and river gravel. For most BST projects in Iceland, the Icelandic Road Administration or ICERA provides the aggregate and the binder for the project with the exception of southwest region. ICERA operates a number of quarries around the country where BST aggregates are produced for new construction, resealing, and maintenance. ICERA doesn´t own aggregate production equipment but it hires a contractor based on a bidding process to produce the amount necessary of each aggregate gradation based on a project schedule for the road network specific to that quarry. At the start of a project, the contractor is granted access to the quarry and he is responsible for loading and hauling the aggregate to the project site. In the contract documents, it is noted that the contractor should not use more aggregate than necessary and in most cases an estimate of aggregate volume is provided. Contract payments are based on square meters but not tonnage of aggregate so the contractor should not have a motive for applying an excessive amount of aggregate, it is cheaper to apply as little as possible without affecting the quality of the finished surface. The most common aggregate gradation types used in Iceland are listed in Table 2.

Table 2 - Most commonly used aggregate gradations in Iceland as specified in Alverk95

Single sized aggregate	Open graded aggregate
4-8mm	0-11mm
8-11mm	0-16mm
8-16mm	0-20mm
11-16mm	

Most BST projects today use the 8-11mm or 11-16mm gradations although a number of other gradation types are used, some of which are not specified in Alverk95. In most cases these changes are made to reduce the production cost by using more chip sizes that would otherwise been thrown out. This is a controversial way to save money as aggregate production costs are a small percentage of the overall cost of a chip seal. Similar savings might be obtained by improving production methods of aggregates.

There are three main factors of concern regarding chip sealing aggregates in Iceland. First of all, studded tires are very common in Iceland. Studs have been used in Iceland since the 1960´s and around 1970, more than 90% of all cars used studded tires. Although the use of studs have been on the decline ever since, still about 52% of cars in the capital Reykjavik were on studded tires according to a study in 2006 (PSN-Samskipti ehf, 2006) . This percentage is a lot higher in other, more rural parts of Iceland. To limit wheelpath rutting due to studded tire wear, good abrasive strength of aggregates are very important (Pétursson, 2006). The second factor of concern is the Icelandic climate. Freezing and thawing cycles are very frequent all over the country during the winter months. Durability and soundness are therefore important characteristics of the aggregate. The third factor is directly related to climate as well. Snowfall is very common during the wintertime in Iceland, especially in the northern part. As a result, snow plowing is a routine winter maintenance activity, which can cause damage by whipping off the aggregate, especially in the non-wheelpath areas. This makes good adhesion, durability and resistance to abrasion all the more important in a chip seal performance. Other factors like ocean saline spray and de-icing materials used in the winter time can increase the deterioration of poor quality aggregates (Pétursson, 2006).

In 2006, a report was published that determined fundamental properties of aggregates in 20 most used ICERA quarries in Iceland. The report studied the form, shape and petrographic type of each quarries' aggregate in great detail. The study measured many characteristics of the aggregates, three of them are of particular relevance in chip sealing; flakiness index, angularity, and fracture rate. Aggregate was divided into size categories and the category 8-16mm, which is commonly used for chip sealing was one of them.

Flakiness index was reported to be from 0% in the best sample to 43% in the worst one. Angularity is another important characteristic for chip seals, the more angular aggregate, the better interlock between the particles. An average of 63% of the aggregate particles was considered angular, 32% sub-angular or sub-rounded, and 5% rounded.

ICERA standard specification, ALVERK 95, specifies a minimum fracture rate as a percentage of aggregate particles with at least one fractured face. The rate is dependent on traffic volume, 40% of particles are supposed to have at least one fractured face when traffic exceeds 1,000 ADT, otherwise, 20% is considered sufficient. The study showed that an average of 71% of particles had at least one fractured face.

The motivation for this study was to develop a relationship between the measured properties of the aggregates and their performance in the field. No study was found that explored that connection.

4.2 Aggregate in Washington State

Chip seal pavements in Washington State are subject to similar wearing forces of those in Iceland, especially in eastern part of the state where freezing and thawing cycles are common and the abuse of snow plows and studded tires are a major concern. Ever since 1969, when a ban on studded tires was lifted, WSDOT has advocated for banning the studs again due to the damage they cause to pavements. Studs are still allowed from November 1st to April 1st in Washington (WSDOT - State Materials Laboratory, 2006). Aggregates in Washington State are mainly high quality basalt. The aggregate is very durable and has high abrasive strengths. The main focus of the aggregate characteristics for chip seals in the state has been on gradation. Aggregate production is done by the contractors who operate the quarries, in most cases, the contractors doing the chip seals use aggregates from their own quarries. This often means that aggregates are hauled long distances to the project sites. The gradations specified in WSDOT´s standard specification are listed in Table 3. The most common gradations to use are ½"-US No.4, 3/8"-US NO.4 and 3/8"-US NO.10 for reseals, and US No.4-0 for choke stone.

Table 3 - Aggregate gradations as specified by WSDOT standard specifications

	Crushed screening percent passing					
Sieve size	3/4" - 1/2"	5/8" - US No.4	1/2" - US No.4	3/8" - US No.4	3/8" - US No.10	US No. 4-0
25mm	100	---	---	---	---	---
19mm	95-100	100	---	---	---	---
16mm	---	95-100	100	---	---	---
12.5mm	0-20	---	97-100	100	100	---
9.5mm	0-5	---	---	70-90	95-100	100
6.35mm	---	---	0-15	---	---	---
4.75mm	---	0-10	0-5	0-5	0-35	76-100
2.4mm	---	---	---	0-3	---	---
2mm	---	0-3	0-2	---	0-10	30-60
0.075mm	0-1.5	0-1.5	0-1.5	0-1.5	0-1.5	0-10
% fracture, by weight, min.	90	90	90	90	90	90

3/8”-US No.4 is most commonly used when the underlying pavement is in good condition with minor deficiencies (WSDOT, 2009 A). The ½” – US No.4 is mainly used in the choke stone method where US No. 4-0 is applied on top of it.

4.3 Asphalt in Iceland

Prior to 2006, cutback asphalt was used as a binder in chip seal projects in Iceland. In the 1990’s a few test sections with asphalt emulsion had been constructed with very variable outcomes, from performing equally to standard cutback asphalt sections to a complete failure (Arason & Árnason, 2008). A lack of production equipment and technical expertise lead to the conclusion that emulsions were not a feasible option for chip sealing at that time. Since then, emulsions have developed and their producers have introduced new emulsions that seemed better fit for Icelandic chip seals. Therefore, from 2003 to 2006, several test sections were constructed using emulsions. The sections were monitored with visual inspections and several reports were written about the study. The performance was better than in previous experiments and in 2005, writing of specifications for emulsions had started. Poor performance of test sections constructed in 2006 was a setback in the process of using emulsions in Iceland and it was decided to withhold further studies and the writing of specifications was discontinued (Arason & Árnason, 2008). In this same year 2006, ICERA did test sections using rapeseed oil as a bonding agent for the asphalt. Those test sections performed well and today, purified rapeseed oil, an interface between pure rapeseed oil and biodiesel, is used on all chip sealing projects in Iceland. Rapeseed oil causes a thicker binder than cutbacks or emulsions and contractors have had some difficulties adopting to this new type of binder and say it is more difficult to handle than the cutbacks. Rapeseed asphalt is fast curing which means that the aggregate chips have to be applied immediately after the binder. The binder has also shown to be more sensitive to dusty aggregate than cutbacks. Experience of rapeseed asphalt in Iceland has shown that it reduces bleeding and the bleeding that occurs is less destructive to the pavement than in cutbacks. Due to bleeding surfaces, ICERA used to pay high amount of compensations to vehicle owners. These compensation payments have been eliminated with the use of rapeseed oil (Hjartarson, 2009).

Rapeseed oil as a bonding agent in asphalt is not a widespread method and reports or documentation about it is hard to find. The rapeseed binder used in Iceland consists of 94.5% asphalt and 5.5% rapeseed oil. The rapeseed oil does not evaporate and is therefore a permanent part of the binder. Distribution temperature is 145°C. Amin, an adhesive modifying agent, is normally added in the mix in the amount of about 0.8% of the weight of the binder.

4.4 Asphalt in Washington State

Asphalt emulsion is the type of binder that is used in almost all US states (Gransberg & James, 2005). WSDOT has a long experience in the use of asphalt emulsions. Emulsions used in the State of Washington are listed in Table 4.

Table 4 - Asphalt emulsion types as listed in WSDOT Standard Specification

Type and grade of asphalt emulsion	**Distributor min spraying temperature °C (or as recommended by the supplier)**	**Max temperature, °C**
CRS-1, CRS-2, **CRS-2P**, CMS-2	52	96
CMS-2S, CMS-2h	52	85
Fog seal:		
CSS-1, CSS-1h, STE-1	21	60

CRS-2P is the most commonly used emulsion for chip seals in Washington. It is a polymer modified, cationic, water based emulsified asphalt. The polymer gives increased viscosity of the residual asphalt, better early chip retention and enhanced flexibility over time (Janisch & Gaillard, 1998). The polymer in CRS-2P should not exceed 3% by volume of emulsion according to WSDOT Standard Specifications.

In general, emulsions are believed to be less sensitive to climatic factors than cutback asphalts such as cold weather and light rain. However, if the ambient and surface temperatures are too high, aggregate and binder adhesion can be severely affected due to reduced binder viscosity (Gransberg & James, 2005).

5 Standard specifications

In the following chapter, standard specifications from Iceland and Washington State will be compared.

Washington State is divided into six regions; Olympic, Northwest, North Central, Eastern, South Central and Southwest regions. Each region has its own headquarters from where it supervises maintenance and rehabilitation of the regions roadway network. The case studies presented later in the paper are both from the North Central region.

ICERA is divided into four regions; South, Southwest, Northwest and Northeast regions. Each region manages projects and maintenance and rehabilitation within the region (ICERA).
From observing the case studies, presented later in the paper, and interviewing professionals from Iceland and Washington State it seems that Iceland and Washington State have many similarities regarding chip sealing. Designs, which involve determining binder and aggregate application rates, are mainly empirical based on experience, no formal design methods are used. The specified application rates are then adjusted according to conditions on each job site. Jurisdictions within Iceland and Washington State use different designs, especially regarding aggregate gradation.

There is a great difference between the standard specifications in Iceland and Washington State. ICERA’s standard, named Alverk95, is from 1995 and has not been updated since. An updating committee has been working on revising the standard for past several years and that revision is still a working progress (Hjartarson, 2009). The structure of the standards makes it somewhat a difficult task to update a specific section like chip sealing as the distinction between them are not as clear as in the WSDOT standards. Being almost 15 years old, the standards are outdated in some sections. As a result, the tender documents are used to further define the standard specifications where needed. Chip spreaders are for example not mentioned in Alverk95 but a self propelled chip spreader is always listed as a specification in tender documents.

WSDOTs standard specifications regarding chip seals are more detailed than the Icelandic standards. They are released every 2 years which means they should always be up to date. For the past 4 years, special efforts have been made to revaluate standard specifications regarding chip seals in Washington State. This revaluation has been a joint effort of WSDOT, pavement contractors, asphalt producers, and the University of Washington. In a big agency like WSDOT, changes aren‘t made with a snap of a finger and despite the 2 year release cycle, changes can still be a lengthy process.

5.1 Equipment and construction

A detailed comparison of the standards can be seen in Appendix 1. Following is an extraction of the main differences found between the specifications regarding equipment and construction.

WSDOT	***ICERA***
Rollers	
Rollers shall not weigh less than 12 tons	Rollers shall weigh 8-12 tons
Aggregate spreading equipment	
Adjustable spread width in 6 inch increments without stopping machine	No specifications on chip spreader
Application of asphalt binder	
Existing surface shall be swept until free from dirt and other foreign matter	No specifications for sweeping
Contractor shall provide a minimum 1,000ft test strip when beginning a chip seal section	Before asphalt application, nozzle accuracy shall be tested according to standards. Tests shall done 2 times each summer
No similar specifications	When emulsion is applied to a roadway with ADT>1,500, up to 25% less emulsion is applied in wheelpaths
Application of aggregate	

All aggregate stockpiles shall be watered down to provide aggregates that are uniformly damp at the time of placement on the Roadway	Aggregates shall be as dry as possible when applied
A minimum of 3 pneumatic tire rollers	No specifications on number of rollers
Choke aggregates shall be applied immediately following the initial rolling of the coarse aggregate	No specifications on applications of choke aggregate
Weather conditions	
Roadway surface temperature at least 13°C	Roadway surface temperature at least 3°C
Air temperature at least 16°C and rising	Air temperature at least 5°C and rising
Air temperature not less than 21°C when falling	No similar specifications
Wind less than 4.5m/s	Asphalt shall not be applied if wind is strong enough to uneven its distribution or if the wind cools the emulsion too much
Roadway surface temperature not more than 60°C	No similar specifications

5.2 Aggregates

Figure 9 displays the difference in standard specification tolerances between the two most used gradations in North Central region in Washington State and in Iceland. The gradation charts clearly illustrates that the most common aggregate classes used in Iceland are bigger and slightly more single sized than those that are most common in Washington.

Both Icelandic gradations allow a 5% passing the No. 200 sieve where WSDOTs standards only allow 1.5%.

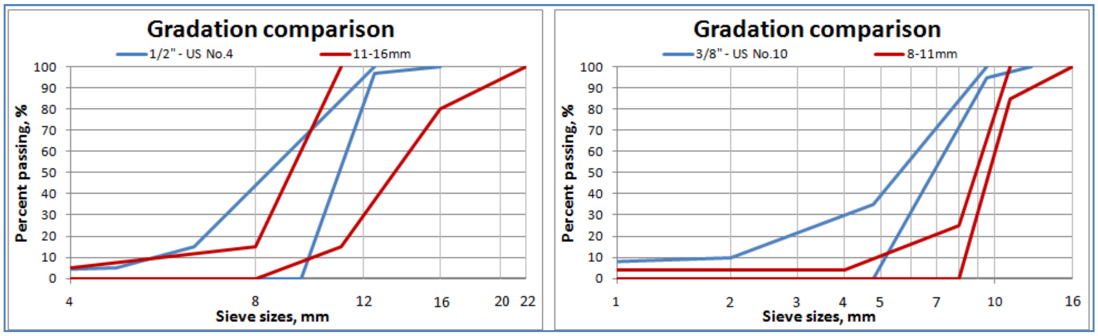

Figure 9 – Standard specification tolerances for common aggregate gradations in Iceland and Washington State

The only aggregate tests that are done on a job to job basis at both agencies are gradation tests. Other tests like LA Wear and degradation tests are taken as needed or when conditions in quarries change.

5.3 Asphalt

Table 5 lists up a comparison in binder application rates between similar aggregate sizes in Iceland and Washington State. The rates from Washington State are taken from the standard specifications. The Icelandic binder rates are derived from tender documents as Alverk95 doesn't specify binder rates for the rapeseed asphalt primarily used in Iceland today. The table shows that ICERA specifies higher binder application rates than WSDOT does.

Table 5 - Comparison between specified binder application rates for similar aggregate gradations in Iceland and Washington

	5/8" US No 4	11-16 mm	1/2" US No 4	8-11 mm
Average chip size	12mm	11mm	9mm	9.5mm
Binder application rate	1.8-2.95 l/m^2	1.8 l/m^2	1.6-2.5 l/m^2	1.6 l/m^2
Residual asphalt	1.2-1.9 l/m^2	1.7 l/m^2	1.04-1.6 l/m^2	1.5 l/m^2

Slightly more uniform aggregate sizes in Iceland require higher binder application rates.

Asphalt binder tests specified in ICERAs ALVERK95 are very rarely performed although they used to be done regularly a few years ago (Hjartarson, 2009).

WSDOT inspectors take two samples from every asphalt hauling truck which are sent to a laboratory where the asphalt is tested according to specifications.

Figure 10 - Taking sample from the asphalt hauling truck

6 Contracting practices

Contracting practices is a major factor affecting the cost and the performance of the chip sealing project. "*The distribution of risk through the chip seal contract can create either an incentive to furnish the best possible quality or a bias to deliver the bare minimum*" (Gransberg & James, 2005).

In the following sections, contracting practices from the two regions will be discussed and compared.

6.1 Tendering

Both agencies invite tenders to bid at their chip seal projects in an open bid where the project is generally awarded to the contractor with the lowest bid given that he fulfills the requirements of each agency.

Common contract sizes for resealing jobs in Iceland for the past two years have been from 3-500,000 m^2. With a 6.3m average width of a roadway, that amounts to 48-80km of a 2 lane road. An average contract size in Washington State is similar, although they can get a lot bigger.

6.2 Contractors

In Washington State there are three or four major chip seal contractors and bidders for a single project are usually two or three. Contractors from Idaho and Oregon have also been making bids for projects close to the state borders.

Major chip seal contractors in Iceland are three to four as well there are a few contractors that mainly bid for projects in their own region. Most common number of bidders is four to six for a single project.

6.3 Qualification of contractors

In Washington State, prequalification of a contractor is required before he can make a bid for any highway, road, or other public work for the state (WSDOT, 2009 B). The prequalification requires a contractor to submit a Standard Questionnaire and a Financial Statement if its net worth exceeds one hundred thousand dollars. In the Standard Questionnaire, the contractor must include information such as;

- Experience with a list of present projects and projects performed past three years
- Experience of principal employees like superintendants and foremen
- A list of available equipment

The contractor needs to specify which field of work he is requesting prequalification. The information submitted is then reviewed by WSDOT and prequalification is granted if the contractor fulfills the following requirements;

- Adequate financial resources or the ability to secure such resources
- The necessary experience, organization, and technical qualifications to perform the proposed contract
- The ability to comply with the required performance schedule taking into consideration all of its existing business commitments
- A satisfactory record of performance, integrity, judgment, and skills; and
- Be otherwise qualified and eligible to receive an award under applicable laws and regulations

  (Washington State Legislature)

The prequalification is granted for one year at a time.

The qualification of contractors in Iceland is different than in Washington State. All contractors are allowed to bid on projects but to be considered for contract award the contractor must fulfill the following requirements;

- Contractor must have worked on at least one comparable project with a contract worth of at least 50% of the project being bid on during past 5 years
- Annual turnover of contractor for past three years must be at least 50% of the project being bid on
- Contractor must have an operating quality management system comparable to ISO 9001 and its administrative employees must have worked according to the system in at least one project

In the bidding documents, the contractor must fill out a list of comparable projects as well as a list of projects where a quality management system has been implemented. In addition to these requirements, the contractor must fulfill a number of financial requirements to be awarded the contract.

6.4 Payments

The basis for contractors payments differ between Iceland and Washington. In Washington the contractor is paid based on the amount used of materials binder and aggregate. The asphalt binder is paid based on tons of material and aggregate in cubic yards for each gradation size. This is one reason WSDOT has three inspectors on each chip seal project to document the amount of material used and to make sure they are not used in excess. There has been a discussion about changing the payment method and basing it on area calculations instead of volumes. The main reason for that is moving the construction risks to a greater degree to the contractor, especially for excess aggregate use.

Chip seal contractors in Iceland are paid based on total square meters of the finished chip seal surface. In most contracts, ICERA provides the contractor the asphalt binder and the aggregate. The materials are provided at known locations listed in the tender documents so the contractor has to include the cost of hauling for binder and aggregate in the square meter unit price, although, two ICERA regions pay the contractor for the hauling of aggregates and binder. The drawback of this system is that when ICERA specifies a certain application rate for binder and aggregate, and supplies all the materials, it is extremely difficult to hold the contractor accountable for any deficiencies that might come up. The lack of inspection mentioned earlier makes this an even bigger problem when the agency has little or no knowledge of the actual rates applied or if specifications were followed.

6.5 Contractor liability

Contractor liability is a controversial issue for both ICERA and WSDOT.

In Iceland, contractors must submit a warrant effective for one year amounting to 15% of the bid amount. In many cases, a one year inspection that evaluates how the pavement has performed for the first year has not been done before the warrant expires (Hjartarson, 2009). Because ICERA in most cases provides all the materials for the chip seal it is very difficult to hold the contractor liable for imperfections of the project. As a result there are very few examples where a contractor has been forced to redo a failed chip sealing project. Cases of serious imperfections, if discovered soon after construction of a chip seal, are often settled in a way that both parties, the contractor and the agency, pay their share of the repair.

In Washington State, the contractor pays no warranty for its chip seal contract. If a serious imperfection is discovered soon after the construction, the conclusion about liability is in most cases the same as in Iceland, the contractor and the agency will share the repair cost.

6.6 Cost

The chart in Figure 11 displays a comparison of cost between the projects in the case studies presented later in the paper plus one other job, SR153. That project was added to the comparison because one of the other two Washington projects, US 2, was incompatible to the other case study jobs. The comparison is based on square meters which might be a bit misleading because the application rates of binder and aggregates vary between the projects. The amounts are bid tab prices, design and engineering costs are not included in the comparison, neither is the cost from quality control or quality assurance, like inspection or material testing.

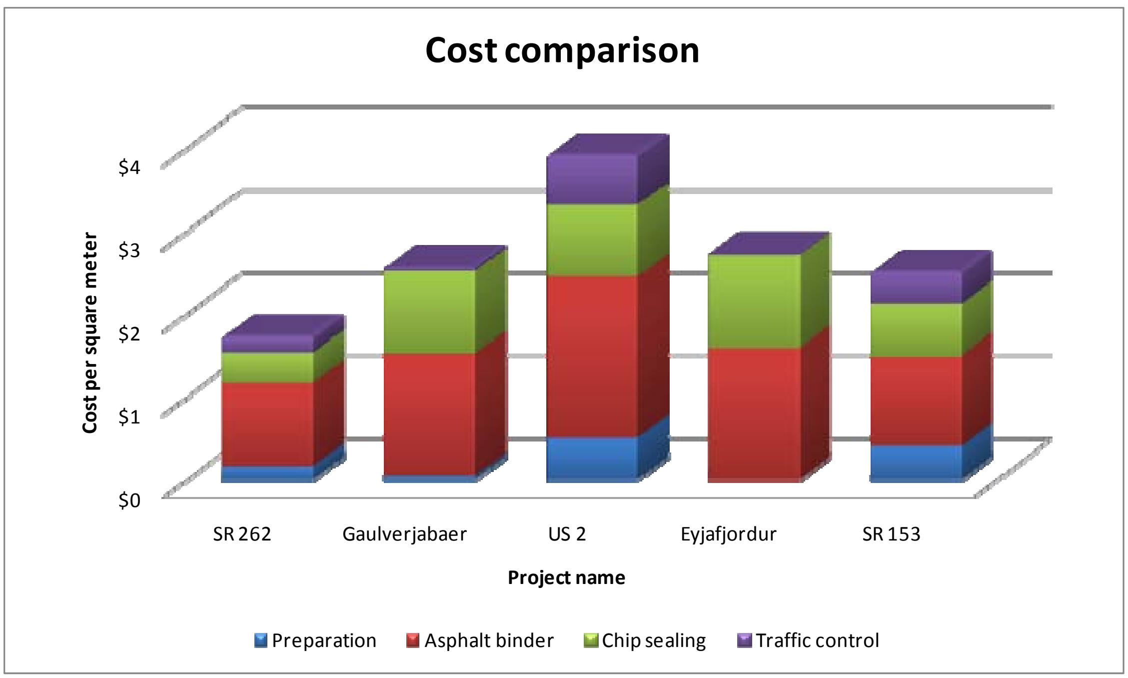

Figure 11 - Cost comparison.

All of the sections are parts of a larger chip seal project except the US 2 project which explains how much higher in cost it is. That project was part of a 13.5 km stretch of HMA overlay. High preparation and traffic control costs for US 2 are because of a relative short section compared to the others and very high traffic volumes of around 12,000 ADT. The

Icelandic projects are more expensive per square meter. The asphalt is more expensive in Iceland as well as the chip sealing procedure itself which includes the aggregate production costs. Preparation and mobilization costs are a lot smaller fraction of the overall cost in Iceland than in Washington. There are normally fewer people working on a chip seal project in Iceland. Providing the contractor asphalt binder and aggregates decreases his overhead cost of the contractor. Traffic control is less extensive in Iceland because of low traffic volumes and pilot cars and flaggers are very rarely used on chip sealing projects.

The calculations are based on an exchange rate of the US Dollar vs the Icelandic Krona of 1:125. This is a fairly low rate of the Krona compared to exchange rates of past several years. If a stronger rate of the Krona were to be used, it would further increase the difference in cost.

7 Construction practices comparison

The construction phase is the most critical part in a chip seals performance and quality. Most deficiencies in a chip seal are related to poor construction practices where standards and agency instructions are not followed. Following is a comparison between construction practices in Iceland and Washington State.

7.1 Equipment

Equipment used in the two regions is similar in type and quality. Using computerized binder and chip spreaders is the norm in both regions. Applying variable rates of binder or aggregate over the roadway section, e.g. in wheelpaths, is hardly ever done. Pneumatic tire rollers are used for rolling but the number of rollers used varies. A minimum of 3 rollers are specified in Washington State but no such specifications are in the Icelandic standards but tender documents say that the contractor should be equipped with sufficient number of rollers so rolling won't hold up the chip sealing. In the case studies presented later in the paper, the Washington projects both had 3 rollers on-site, but the Icelandic projects only had one. Having only one roller must be insufficient according to tender documents that say that rollers should complete 4-5 complete coverages of the roadway and the first coverage must never be more than 30m behind the chip spreader.

Most sweepers used in Iceland are rotary brooms mounted at the front of a pickup truck, tractors or small hauling trucks. Pick up sweepers and vacuum trucks are rarely used. Specialized rotary brooms are the most common ones used in Washington although the use of pick up sweepers is a bit more common than in Iceland.

7.2 Preparation

WSDOT specifies sweeping of the existing surface and it is always done before the application of binder commences. No such requirement is in ICERA's specifications, ALVERK95, but tender documents specify it if the inspector thinks it's necessary. In some exception cases, shoulders are swept prior to binder application, but sweeping the entire roadway is barely ever done.

7.3 Traffic control

Traffic control is a very important part of chip sealing as the traffic contributes to the orientation and embedment of the chips and for the best results, traffic speed must be kept at bay during the reorienting of the chips (Gransberg & James, 2005). WSDOT's Standard Specifications has a detailed section about traffic control and ICERA has published a brochure called Project Site's Signage (Merking Vinnusvæða) which is referred to in tender documents. ICERA also rates each project's traffic control and signage and gives the contractor a grade for its effort based on a rating system specified in the tender documents. In most Washington chip seal projects a pilot car and flaggers are used to control the traffic which is not a common practice in Iceland. This is in most part because traffic volume is in most cases greater in Washington State than in Iceland. Both agencies reduce speeds to about 50km/hr and the speed limit can be enforced by police. Sweeping is done as soon as practical in both regions, but due to traffic volume, projects in Iceland usually need more time to acquire satisfactory reorientation of chips. Icelandic car owners are required to have a front windshield insurance which means windshields are replaced "free of charge" if they crack due to loose chips on the road.

7.4 Inspection

There is significant difference in inspection practices between the two regions. Those differences were evident when the case studies were observed. In Washington (North Central Region) three inspectors are on-site while the chip sealing is performed. The main inspector oversees the whole project, communicates with the site foreman from the contractor, adjusts the binder and aggregate application rates if necessary, and makes sure the traffic control is up to standards. A second inspector is observing and documenting the aggregate quantity and application rate, and the third one is observing and documenting the asphalt binder quantity and application rate. Inspectors documenting the application of binder and aggregate log the amount and location of each shot of the binder distributor and every aggregate truck that is dumped into the spreader. An example of these log documents are shown in appendix 2. Based on those logs, fairly accurate application rates of binder and aggregate can be calculated. These logs can also be helpful later on in evaluating imperfections that might come up.

Inspection in Iceland is a lot less intensive than in Washington as it is merely done on visiting basis. The inspector is not on the project the entire time the chip seal is performed and no quantity measurement or logging is done. In some cases, no on-site inspection is done for an entire section of a chip seal. This huge difference in inspection practices is in part because of different payment methods as discussed later in the paper. Although the payment method does not require as strict inspection of quantities as in Washington this lack of inspection in Iceland undeniably recoils upon the quality of the finished product. A comprehensive inspection during the construction phase is critical for the quality of the finished surface (Gransberg & James, 2005).

8 Chip seal design methods

There are two chip seal design methods in use in America; the Kearby method and the McLeod method. Some states, like Washington State, use their own empirical design method based on past experience while others use no formal method at all. The Kearby method was developed in 1953 and the modified Kearby method was introduced in 1974. The McLeod method was developed in 1969. Other countries like United Kingdom, South Africa, Australia and New Zealand are using their own design methods with good results (Gransberg & James, 2005). Later in this project, the McLeod method and Australian design method will be used to evaluate chip seal designs from the case studies in Iceland and Washington State.

Both design methods base their calculations mainly on aggregate size and shape, texture of the existing surface and traffic conditions. In this chapter, these design methods will be introduced.

8.1 McLeod design method

Norman William McLeod was a Canadian engineer and researcher who significantly contributed to worldwide highway engineering. During his career he worked on challenging road projects which pushed the boundaries of what had been done before (Asphalt Institute, 1998). In 1969, McLeod introduced a method for calculating asphalt and aggregate distribution rates for a given roadway, known as the McLeod method. It is based on two basic principles:

- The application rate of a given cover aggregate should be determined so that the resulting seal coat will only be one stone thick. This amount of aggregate will remain constant, regardless of the binder type or pavement condition.
- The voids in this aggregate layer need to be 70% filled with asphalt cement for good performance on pavements with moderate levels of traffic.
  (Janisch & Gaillard, 1998)

The binder application rate is determined by aggregate characteristics, traffic volume on the roadway, existing surface characteristics and residual asphalt content of the binder.

The aggregate application rate is depended on aggregate characteristics and traffic volume on the roadway.

These factors will be introduced in the following paragraphs.

8.1.1 Median Particle Size, M (mm):

The Median Particle Size is the theoretical sieve size which 50% of the aggregate passes. Figure 12 shows how Median Particle Size of WSDOT's gradation 1/2"-US No.4 is determined.

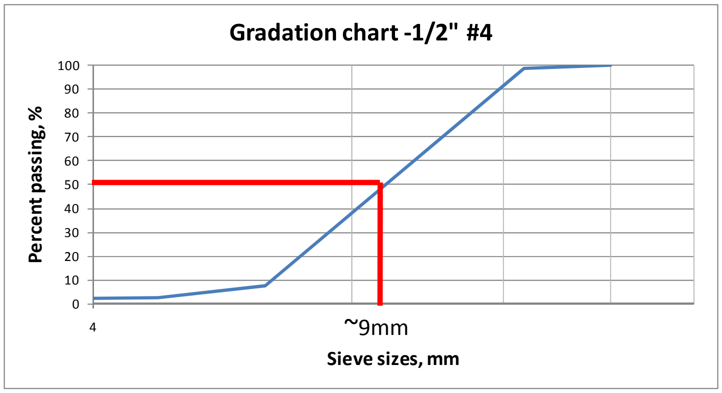

Figure 12 - Median particle size

8.1.2 Flakiness Index, FI (% decimal):

Flakiness Index is a measure of the shape of the aggregate. With a small sample, it measures how much percentage of the aggregate is flat and elongated. One way of estimating the index is with a steel plate that has five slots in it for different sieve sizes; 4.75, 6.3, 9.5, 12.5 and 19mm. Slot nr 1 is for chips retained on the 4.75mm sieve and so on (Janisch & Gaillard, 1998). The chips are considered flat or elongated if they fit through the slots. The index is calculated by Equation 1:

$$FI = \frac{W_F}{W_C} \quad (1)$$

Where;

W_F = weight of flat and elongated particles in sample (kg)

W_C = weight of all particles in sample (kg)

8.1.3 Average Least Dimension (ALD), H (mm):

The Average Least Dimension is determined by the Median Particle Size and the Flakiness Index. Because traffic will force the chips to lie on their flat side, especially in the wheelpaths, it uses the Flakiness Index to reduce the Median Particle Size. This is done so that binder rate for the wheelpaths can be accurately calculated to achieve the 70% embedment described earlier (Janisch & Gaillard, 1998). The Average Least Dimension is calculated by Equation 2:

$$H = \frac{M}{1.139285 + 0.011506 * FI} \quad (2)$$

Where;

M = Median Particle Size (mm)

FI = Flakiness Index (%)

8.1.4 Loose unit weight of aggregate, W (kg/m^3):

Loose unit weight of the aggregate is used for determining how much air void there is between particles in a loose, uncompacted condition. It is used when calculating how much binder is needed to embed the aggregate 70% in binder. One sized gradation will result in lower loose unit weight as it has more air voids between the chips than well graded aggregate. Loose unit weight of aggregate is determined according to ASTM C 29 – Standard Test Method for Bulk Density. The aggregate is poured into a container of a specific volume and weighed, the loose unit weight is than calculated by Equation 3:

$$W = \frac{W_{A+C} - W_C}{V_C} \quad (3)$$

Where;

W_{A+C} = Weight of aggregate and container (kg)

W_C = Weight of container (kg)

V_C = Volume of container (m^3)

8.1.5 Bulk Specific Gravity of aggregate, G:

Bulk Specific Gravity is the ratio of the weight of a unit volume of aggregate to the weight of an equal volume of water (INDOT, 2005). It is determined by the AASHTO T 85 – Standard Method of Test for Bulk Specific Gravity. It is used for determining air voids in the loose aggregate and is calculated by Equation 4:

$$G = \frac{W_D}{W_{SSD} - W_W} \quad (4)$$

Where;

W_D = Weight of oven dry aggregate (kg)

W_{SSD} = Weight of saturated surface dry aggregate (kg)

W_W = Weight of aggregate in water (kg)

8.1.6 Voids in the loose aggregate, V (% decimal):

Voids in the loose aggregate approximates the voids between the aggregates once they have been applied by the chip spreader and before they are rolled. For one-size aggregate this value is close to 50% but drops to 30% after initial rolling and to 20% when traffic has oriented the stones on their flattest side and created good interlock. If traffic is not sufficient, the voids will be around 30% which means more binder has to be applied for sufficient embedment. The value is calculated by Equation 5:

$$V = 1 - \frac{W}{1{,}000 * G} \quad (5)$$

Where;

W = Loose unit weight of aggregate (kg/m^3)

G = Bulk specific gravity of aggregate

8.1.7 Aggregate absorption, A (% decimal):

Aggregate absorption indicates how porous the tested material is. It is tested according to test method AASHTO T-84. This test estimates the increase in weight of the aggregate due to water filling the pores of the material, not including water adhering to the outside surface of the particles (INDOT, 2005). It is calculated according to Equation 6:

$$A = \frac{W_{SSD} - W_D}{W_D} \quad (6)$$

Where;

W_{SSD} = Weight of saturated surface dry aggregate (kg)

W_D = Weight of oven dry aggregate (kg)

8.1.8 Aggregate Absorption Factor, A_F:

The Aggregate Absorption Factor is a correction of the binder application rate based on aggregate absorption. If the aggregate is porous it absorbs some of the binder into its pours which decreases the amount of binder left on the roadway surface. McLeod suggested a 0.09l/m^2 increase in binder application rate for aggregate absorption around 2%. The Minnesota Seal Coat Handbook recommends increasing the binder rate for aggregates with absorption rates higher than 1.5% (Janisch & Gaillard, 1998).

8.1.9 Traffic correction factor, T:

Traffic volume is an important factor when determining asphalt binder application rates. Traffic volume is measured in number of vehicles travelling the roadway per day or Average Daily Traffic, ADT. Traffic forces the chips to lay on their flat side. If no traffic was on the roadway the chips would hold their orientation after rolling has finished. In that case, some of the particles would not be laying on their flat side which means more binder is needed to reach the desired 70% embedment of aggregate (Janisch & Gaillard, 1998). McLeod design method uses Table 6 to select the traffic correction factor.

Table 6 - Traffic correction factor

Traffic, ADT	Traffic correction factor, T
<100	0.85
100-500	0.75
500-1000	0.7
1000-2000	0.65
>2000	0.6

8.1.10 Traffic wastage factor, E:

McLeod method features a traffic wastage factor that accounts for the aggregate particles that are whipped off the roadway by traffic. The amount of whipped off aggregate depends on traffic volume and speed. Aggregate application rate has to be increased by the wastage factor. Minnesota Seal Coat Handbook assumes the values 5% for low volume, residential type traffic and 10% for rural roadways with higher speeds (Janisch & Gaillard, 1998).

8.1.11 Surface correction factor, S:

Condition of existing surface is an important factor in determining the binder application rate. A badly pocked and porous surface can absorb a significant part of the binder, resulting in insufficient embedment of aggregate leading to excessive loss of chips. On the other hand, a bleeding surface needs less binder for reaching the desired embedment. The surface correction factor estimates the binder rate correction based on the existing surface condition, see Table 7.

Table 7 - Surface correction factor

Existing pavement texture	Correction, l/m^2
Black, flushed asphalt	-0.04 to -0.27
Smooth, non porous	0.00
Slightly porous and oxidized	+0.14
Slightly pocked, porous and oxidized	+0.27
Badly pocked, porous and oxidized	+0.40

8.1.12 Residual asphalt content of binder, R (% decimal):

Residual asphalt content is the amount of binder remaining on the roadway after evaporation of the cutter or water (Janisch & Gaillard, 1998).

8.1.13 Aggregate application rate, C (kg/m^2):

Based on the aforementioned factors, aggregate application rate can now be calculated by Equation 7:

$$C = (1 - 0.4V) * H * G * E \quad (7)$$

Where;

V = Voids in the loose aggregate (% decimal)

H = Average Least Dimension (mm)

G = Bulk Specific Gravity of the aggregate

E = Wastage factor for traffic whip off

8.1.14 Binder application rate for wheelpaths, B_W (l/m^2):

Binder application rate can now be calculated by Equation 8:

$$B = \frac{0.4 * H * T * V + S + A}{R} \quad (8)$$

Where;

H = Average least dimension (mm)

T = Traffic correction factor

V = Voids in loose aggregate (% decimal)

S = Surface correction factor

A = Aggregate absorption factor

R = Residual asphalt content of binder (% decimal)

8.1.15 Binder application rate for non-wheelpath areas, B (l/m^2):

The Minnesota Seal Coat Handbook introduces a modification of the binder application rate for non-wheelpath areas. It suggests a slightly higher application rate of binder in non-wheelpath areas to minimize snow plow damage (Janisch & Gaillard, 1998). The equation for calculating the application rate is the same as for wheelpaths, except it uses the median particle size (M) instead of average least dimension because the aggregate particles are less likely to be oriented on their flat side in non-wheelpath areas. The application rate is calculated by Equation 9:

$$B = \frac{0.4 * M * T * V + S + A}{R} \quad (9)$$

Where;

M = Median particle size (mm)

T = Traffic correction factor

V = Voids in loose aggregate (% decimal)

S = Surface correction factor

A = Aggregate absorption factor

R = Residual asphalt content of binder (% decimal)

8.2 Australian design method

Australia has performed a great deal of research on chip seals and has developed a sophisticated design method. Australia's chip seals have significant longer service life, about 9.6 years, than average service life in Iceland and Washington State. Total lane miles of chip seals in Australia are almost double the length of the US, or 273,000 miles. (Gransberg & James, 2005). Austroads is the association of Australian and New Zealand road transport and traffic authorities. In 2006, Austroads published an update of its Sprayed Seal Design Method. The catalog is a detailed description of design methods for different kinds of chip seals (Austroads, 2006). Following is a brief introduction of the design method of single/single seals that will be used in the case studies section in the project. The method is somewhat similar to the McLeod method since some of the components used are the same. In those cases, a reference will be made to the description of the McLeod design method described in previous section.

8.2.1 Traffic Volume, V/L/D:

Traffic volume is expressed in vehicles per lane per day, V/L/D, based on average daily traffic, ADT. Specific rules apply for multiple lane roadways or for special sections like overtaking lanes and on and off ramps but for a normal two way roadway with one lane in each direction, V/L/D equals ½ ADT. Heavy vehicle traffic is also accounted for by the percentage of equivalent heavy vehicles, EHV. Heavy vehicles are divided into Heavy Vehicles (HV) and Large Heavy Vehicles (LHV), where large heavy vehicles are heavy truck/trailer combinations with seven or more axles. Equivalent heavy vehicle percentage is found according to equation 10.

$$EHV\% = HV\% + LHV\% * 3 \quad (10)$$

Where;

HV% = percentage of heavy vehicles

LHV% = percentage of large heavy vehicles

8.2.2 Basic void factor, Vf (l/m²/mm):

The basic void factor is related to traffic and is determined from Figures 13 and 14.

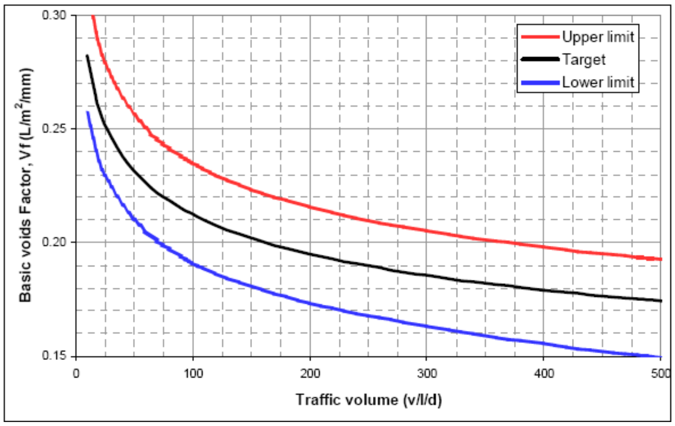

Figure 13 - Basic void factor, Vf, for traffic volumes 0-500 V/L/D. Source (Austroads, 2006)

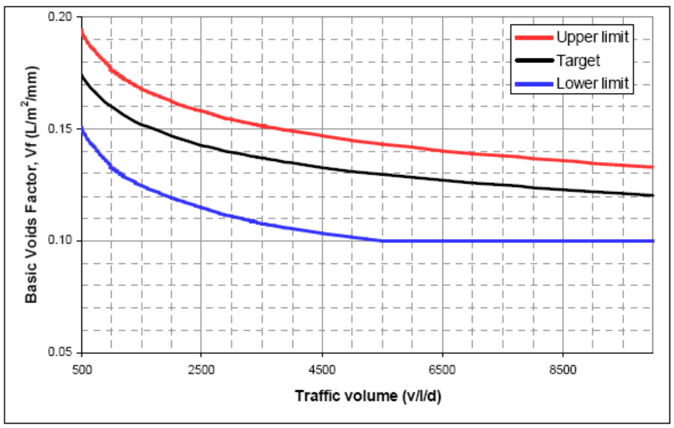

Figure 14 - Basic void factor, Vf, for traffic volumes 500-10,000 V/L/D. Source (Austroads, 2006)

8.2.3 Aggregate flakiness index, FI (%):

Same index as used in the McLeod method see chapter 8.1.2.

8.2.4 Adjustments to basic void factor:

Adjustments to the basic void factor are made based on aggregate shape and traffic effects.

8.2.4.1 Adjustment for aggregate shape, Va ($l/m^2/mm$):

Adjustments on the basic void factor for aggregate shape are based on the type of aggregate, its shape and flakiness index according to Table 8.

Table 8 - basic void factor adjustments for aggregate shape

Aggregate type	Aggregate shape	Flakiness index	Shape adjustment, Va
		%	$L/m^2/mm$
Crushed or partly crushed	Very flaky	>35	Not recommended for sealing
	Flaky	26-35	0 to -0.01
	Angular	15-25	0
	Cubic	<15	+0.01
	Rounded	n/a	0 to +0.1
Not crushed	Rounded	n/a	+0.01

8.2.4.2 *Adjustment for traffic effects, Vt ($l/m^2/mm$):*

Adjustment for traffic effects are based on equivalent heavy vehicle percentage and the roadway alignment according to Table 9.

Table 9 - basic void factor adjustments for traffic effects

Traffic	Adjustment to Basic Voids Factor, $L/m^2/mm$			
	Flat or downhill		Slow moving - climbing lanes	
	Normal	Channelized*	Normal	Channelized*
On overtaking lanes of multi-lane rural roads where traffic is mainly cars with <10% of HV	+0.01	0.00	n/a	n/a
Non-trafficked areas such as shoulders, medians, parking areas	+0.02	n/a	n/a	n/a
0 - 15% Equivalent Heavy Vehicles	0	-0.01	-0.01	-0.02
16 - 25% Equivalent Heavy Vehicles (EHV)	-0.01	-0.02	-0.02	-0.03
26 - 45% Equivalent Heavy Vehicles (EHV)	-0.02	-0.03	-0.03	-0.04**
>45% Equivalent Heavy Vehicles (EHV)	-0.03	-0.04**	-0.04**	-0.05**

* Channelisation - a systemof controlling traffic by the introduction of an island, or islands, or markings on a carriageway to direct traffic into predetermined paths, usually at an intersection or junction. This also applies to approaches to bridges and narrow colverts

** If adjustments for aggregate shape and traffic effects result in reduction in Basic Void Factor of 0.4 $L/m^2/mm$, consider alternative treatments

8.2.5 Design void factor, VF ($l/m^2/mm$):

Design void factor can now be calculated according to equation 11.

$$VF = Vf + Va + Vt \quad (11)$$

Where;

Vf = Basic void factor ($l/m^2/mm$)

Va = Adjustment for aggregate shape ($l/m^2/mm$)

Vt = Adjustment for traffic effects ($l/m^2/mm$)

8.2.6 Average least dimension of aggregate, ALD (mm):

Average least dimension of aggregate is calculated by equation 2, see chapter 8.1.3.

8.2.7 Emulsion factor, Ef:

Basic binder application rate is multiplied by the emulsion factor before allowances. If bitumen content of emulsion is higher than 67% the emulsion factor is 1.1, otherwise 1.0. This is to compensate for the reduced reorientation of the aggregate due to increased binder stiffness after initial curing in high bitumen content binders.

8.2.8 Polymer modified factor, Pf:

The polymer modified factor is selected according to Table 10.

Table 10 - polymer modified factor. Source (Austroads, 2006)

Class of PMB	PMB factor	Type of treatment
		Aggregate retention (AR)
S10E	1.1	The factors for AR may be increased by 0.1 on low traffic applications, but reduced by 0.1 on high to very high traffic applications and/or high temperature locations in order to minimise flushing.
S35E	1.1	
		Holding treatment (HT)
S10E	1.2	The factors for HT may be increased by 0.1 on low traffic applications, but reduced by 0.1 on high to very high traffic applications and/or high temperature locations in order to minimise flushing.
S35E	1.2	
S45R/S15RF	1.3	
		Weak pavements (WP)
S20E	1.3	The factors for WP may be increased by 0.1 on low traffic applications where maximum waterproofing is desired and the potential for flushing is low, but reduced by 0.1 on very high traffic volume applications.
S45R/S15RF	1.3	
		As a waterproofing seal under OGA (not a SAMI)
S10E, S35E	1.3	Being placed under open graded asphalt, there is little risk of bleeding and the factors should not require further adjustment, although they may be increased, if required, by 0.1 to provide maximum waterproofing.
S45R, S15RF	1.4	
		High Stress Seal (HSS)
S10E, S35E	1.0	Generally these factors should not be adjusted.
S20E, S45R, S15RF	1.1	They may be reduced, if required, by 0.1 on very high traffic applications and/or hot to very hot locations to minimise flushing or binder pick-up.
M500/170	1.1	
		Strain Alleviating Membrane (SAM)
S10E	1.2	The SAM factors are designed to provide the maximum practicable binder application rate to optimise resistance to reflective cracking and to waterproof the pavement. They may be reduced, if required, by 0.1 on very high traffic applications and/or hot to very hot locations to minimise flushing or binder pick-up.
S20E	1.3	
S35E	1.2	
S45R, S15RF	1.4	
		Strain Alleviating Membrane Interlayer (SAMI)
S25E	1.6	The SAMI factors are designed to optimise the resistance to reflective cracking under Dense Graded Asphalt. The factors may be increased by as much as 0.5 when the SAMI is designed to minimise reflective cracking under Open Graded Asphalt.
S55R, S20RF	1.8	

The most commonly used modifiers are for aggregate retention, resulting in a factor of 1.1 applied to the basic binder application rate.

8.2.9 Basic binder application rate, Bb (l/m^2):

The basic binder application rate is calculated with equation 12.

$$Bb = Vf * ALD * Ef * Pf \quad (12)$$

Where;

Vf = design void factor ($l/m^2/mm$)

ALD = average least dimension of aggregate (mm)

Ef = emulsion factor

Pf = polymer factor

8.2.10 Adjustments to basic binder application rate:

A number of adjustments and allowances are made to the basic binder application rate.

8.2.10.1 Surface texture allowance, As (l/m²):

Binder application rate is adjusted according existing surface's texture. In the Austroads Sprayed Seal Design Method report is says that "*Texture measurements should be taken at least every 400 to 500 m or where there is a visual change in texture, such as a change to a seal of different aggregate size*." Texture depth measurements are done with a sand patch method where a certain area of the existing surface of the roadway is spread with sand. The volume of sand that fills the surface voids determines the surface texture (Gransberg & James, 2005). The surface texture allowance is determined by Table 11.

Table 11 - Surface texture allowance for existing surfacing, As. Source (Austroads, 2006)

Aggregate size of proposed seal	Measured texture depth (mm)	Surface texture allowance (L/m²)
Existing: 14, 16 or 20 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.6	Note 2
	0.7 to 0.9	+0.1
	1.0 to 1.3	+0.2
	1.4 to 1.9	+0.3
	2.0 to 2.9	+0.4
	>2.9	+0.5
10 mm	0 to 0.3	-0.1
	0.4 to 0.5	0
	0.6 to 0.7	+0.1
	0.8 to 0.9	+0.2
	1.0 to 1.3	+0.3
	1.4 to 1.8	+0.4
	>1.8	Note 3
14 mm	0 to 0.3	-0.1
	0.4 to 0.5	0
	0.5 to 0.6	+0.1
	0.6 to 0.7	+0.2
	0.8 to 0.9	+0.3
	1.0 to 1.3	+0.4
	1.4 to 1.8	+0.5
	>1.8	Note 3
Existing: 10 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.9	+0.1
	1.0 to 1.4	+0.2
	1.5 to 2.0	+0.3
	2.1 to 2.7	+0.4
	>2.7	+0.5
10 mm	0 to 0.3	Note 1
	0.4 to 0.7	+0.1
	0.8 to 1.1	+0.2
	1.2 to 1.7	+0.3
	>1.7	Note 3
14 mm	0 to 0.2	Note 1
	0.3 to 0.6	+0.1
	0.7 to 0.9	+0.2
	1.0 to 1.2	+0.3
	1.3 to 1.7	+0.4
	>1.7	Note 3

Aggregate size of proposed seal	Measured texture depth (mm)	Surface texture allowance (L/m²)
Existing: 5 or 7 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.9	+0.1
	1.0 to 1.5	+0.2
	1.6 to 2.2	+0.3
	2.3 to 3.2	+0.4
	>3.2	+0.5
10 mm	0 to 0.3	Note 1
	0.4 to 0.7	+0.1
	0.8 to 1.1	+0.2
	1.2 to 1.8	+0.3
	>1.8	Note 3
14 mm	0 to 0.2	Note 1
	0.3 to 0.6	+0.1
	0.7 to 0.9	+0.2
	1.0 to 1.4	+0.3
	1.5 to 2.0	+0.4
	>2.0	+0.5
Existing: asphalt/slurry surfacing		
All	0 to 0.1	0
	0.2 to 0.4	+0.1
	0.5 to 0.8	+0.2
	0.9 to 1.4	+0.3
	>1.4	+0.4

Notes:

1. Embedment considerations dominant
2. Specialised treatments necessary
3. This treatment might not be advisable depending on the shape and interlock of aggregates so alternative treatments (surface enrichment, small size seal or others) should be considered
4. For application of aggregate sizes greater than 14 mm, adopt allowances applicable to 14 mm aggregate.

8.2.10.2 Embedment allowance, Ae (l/m²):

If the existing surface is soft enough for the chip sealing aggregate to penetrate it, embedment allowance will decrease the binder rate. The embedment allowance is mostly used in initial sealing jobs, not in reseals.

8.2.10.3 Binder absorption by pavement adjustment:

Binder absorption by pavement is mainly aimed at initial treatments. If an existing chip seal or HMA pavement is visibly open and porous, other measures have to be considered prior to chip sealing like primesealing.

8.2.10.4 Binder absorption by aggregate:

Binder absorption by aggregate is normally not a problem and does usually not exceed 0.1l/m^2 (Austroads, 2006).

8.2.10.5 Residual content of binder, R (% decimal):

Residual asphalt content is the amount of binder remaining on the roadway after evaporation of the cutter or water (Janisch & Gaillard, 1998).

8.2.11 Design binder application rate, Bd (l/m^2):

Design binder application rate is calculated by equation 13:

$$Bd = \frac{Bb + As + Ae + Ap + Aa}{R} \quad (13)$$

Where;

Bb = basic binder application rate (l/m^2)

As = surface texture allowance (l/m^2)

Ae = embedment allowance (l/m^2)

Ap = binder absorption by pavement (l/m^2)

Aa = binder absorption by aggregate (l/m^2)

R = residual content of binder (% decimal)

8.2.12 Aggregate application rate (m^2/m^3)

Aggregate application rate for asphalt emulsions is calculated according to Tables 12 - 14, depending on aggregate sizes and the binder type.

Table 12 - Aggregate spread rate for sizes >10mm with emulsions

Application		Aggregate spread rate, (m^2/m^3)	
		Traffic < 200 v/l/d	**Traffic > 200 v/l/d**
Single layer of aggregate		750 / ALD	700 / ALD
Layer of large aggregate plus scatter coat of 7mm or smaller	First layer	800 / ALD	750 / ALD
	Scatter layer	400 - 600	400 - 600

Table 11 displays the aggregate application rate for a single layer of aggregate of 10mm or bigger. It also gives an application rate of the same layer with a scatter coat or choke seal layer applied on top of it.

Table 13 - Aggregate spread rate for sizes <7mm with emulsions

Seal type	Number of aggregate thicknesses	Rate (m^2/m^3)
Seal / reseal	1	260 - 290
	>1	200 - 250
Scatter coat (choke seal)	1	400 - 600

Table 12 lists the application rate for aggregate sizes smaller than 7mm. It also gives the rate of a scatter coat or choke seal. Both tables give the application rate in m^2/m^3.

Table 14 - Aggregate spread rates for polymer modified binders

Traffic conditions	Aggregate spread rate m^2/m^3
Traffic < 300 v/l/d	750 / ALD
Traffic > 300 v/l/d	800 / ALD

Aggregate application rate for polymer modified binders are listed in table 14. Loose unit weight of aggregate is needed to calculate the application rate in kg/m^2.

9 Case studies

In the following chapter, four chip seal case studies will be presented, two from Iceland and two from Washington State. The case studies from Iceland are from ICERA’s Northeast and South regions. Both case studies are reseals of previously chip sealed surfaces. The project from the south region, or R 33, is a typical Icelandic chip seal project with a single application of binder and 8-16mm aggregate. The chip seal design in the Northeast region project, R 829, is less common in Iceland. It is a choke stone design with a single layer of asphalt binder and two layers of aggregate, 11-16mm and 8-11mm.

The projects from Washington State are both from its North Central region and both of them use a fairly common design for that region. The first project, US 2, uses a choke stone design method with a single layer of asphalt emulsion and two layers of aggregate, 6-12mm chips (1/2” US No.4) for the first layer and 0-5mm chips (US No.4-0) as a second layer or choke layer. The second project is on SR 262 south of Moses Lake. It uses a single layer of binder covered by a single application of aggregate. The aggregate gradation is 5-12 mm (3/8” US No. 10).

All four projects were visited twice, at the time of construction and again in 1-3 weeks time. The projects construction will be discussed and evaluated and their designs compared to the Australian and McLeod design methods. It should be noted that binder application rates calculated by the McLeod method are binder application values for non wheelpath areas as described in section 8.1.15. Values of every component in the calculations can be found in Appendix 3, as well as a detailed illustration on design calculations for one of the projects, the US 2 project in Washington.

9.1 US 2 – northwest of Leavenworth

This project was a 16 km stretch of US 2, northwest of Leavenworth. Most of the paving was HMA except for a 2.5 km stretch that is scheduled to be realigned in 2 years. Chip sealing was used on that section as a short term wearing course to prevent further disintegration of the roadway surface. Table 15 lists the major components and influencing factors of the project.

Table 15 - US highway 2 near Leavenworth

US 2- Leavenworth	
Date visited	7. 1. 2009
Contractor	Central Washington Asphalt
Area of total project	0.13 km^2
Area of studied section	20,024 m^2 (16% of totoal project)
Length of studied section	2.5 centerline km
Number of lanes	2
Weather condition, noon	
Temperature	26 °C
Wind speed	2 m/s
Humidity	25%
Cloud cover	Clear
Existing surface	HMA
Surface condition	Fair
Binder	CRS-2P
Binder temperature	65-75 °C
Asphalt distributor	Bear Cat CRC
Asphalt distribution rate	2.5 l/m^2
Residual asphalt content	~65%
Aggregate gradation	1/2" US no 4
Choke gradation	US No. 4-0
Chip spreader	Bear Cat CRC
Chip distribution rate	21 kg/m^2
Choke stone distributor	Bear Cat CRC
Choke distribution rate	3.6 kg/m^2
Rollers	
Make and model	ISR PT 125R
Type	Pneumatic tire roller
Weight	10 tons
Number of rollers	3

The project was visited on the 1st of July 2009. The contractor was Central Washington Asphalt who was the lower of two bidders with $1,683,781 for the entire combined project, HMA and chip seal, as described above. The bid was 23% under the engineering estimate (WSDOT, 2009 D). Chip sealing started at 9am and was finished about 2pm in the afternoon.

Weather conditions were very good, warm, sunny and calm. US 2 has a significant amount of traffic with around 12.000 ADT (WSDOT, 2008). Chip sealing in Washington is normally not done on a roadway so heavily traveled, but because the realignment of that section is scheduled in 2 years, HMA was considered too expensive for a short term surface layer. The contractor had good traffic control with a pilot car and flaggers and although the traffic volume exceeded WDOTs threshold it presented no major problems.

The chip seal design was a choke stone seal with 1/2”-US N0.4 (6-12 mm) as the initial aggregate application and a US No.4-0 (0-5 mm) as the choke stone. The existing surface was in fair condition. Some thermal cracking was visible but no severe distress of the existing pavement was observed. A part of one lane had been paved with thin HMA prior to the chip seal to close up the surface where it had been severely cracked. The underlying HMA had not been milled before the HMA lift was applied, resulting in a thin edge along the center of the roadway, see Figure 15. This edge could be a cause of concern because the roadway does receive a significant amount of snow each year and snowplows are very likely to cause damage on this edge. It is also a potential hazard for motorcycles.

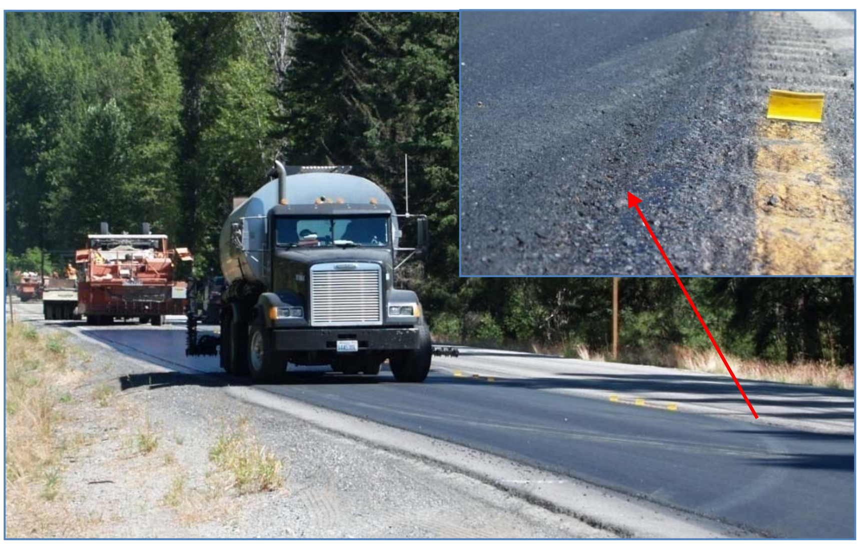

Figure 15 - Thin HMA had been applied prior to chip sealing on a severe cracked section

The binder used for this chip seal was CRS-2P which is the most commonly used binder in the State. It was spread with a computerized distributor at a rate of 2.49 l/m^2 which is at the higher limit in the standard specifications. First layer of aggregate was, 1/2”-US No.4, was applied with a Bearcat computerized distributor at a rate of 21 kg/m^2. The choke stone, US

No.4-0, was applied with a second Bearcat distributor at a rate of 3.6 kg/m^2. Both rates are according to shot notes taken by the inspectors on the project. The choke stone distributor was not able to distribute the aggregate over the whole section of the roadway, therefore an extra pass was needed to cover the last two feet of the roadway shoulder. When the first layer of aggregate had been applied, the rollers made at least 2 complete coverages of the roadway before the choke stone spreader applied the second layer. The choke aggregate was not always applied immediately after the initial rolling like specified in the standard specifications. At one time, the observed time from the application of the first aggregate layer to the application of the choke stone was 15 minutes. It was clear that the top film of the binder had developed a curing film well before the application of the choke, see Figure 16. This will decrease the adhesion between the choke aggregate and the asphalt binder.

Figure 16 - 10 minutes after aggregate application. Binder has started to cure as can be seen on the black film and the brown color underneath the stone that was removed. Choke stone was not applied until 5 minutes later.

Few hours after construction, when cars were travelling on 30-40 mph on the roadway, it could be seen that the choke stone material was very dusty, see Figure 17. WSDOT Standard Specifications allows a maximum of 10% passing the 0.075 mm (No. 200) sieve for the US No. 4-0 which will inevitably cause a lot of dust on the roadway following its application. In most US states the limits on the 0,075 mm sieve is 1-2% for choke stone aggregates.

Figure 17 - Result of a dusty choke stone.

In long portions of the section, bleeding in the wheelpaths was also apparent as a result of a high binder application rate, see Figure 18.

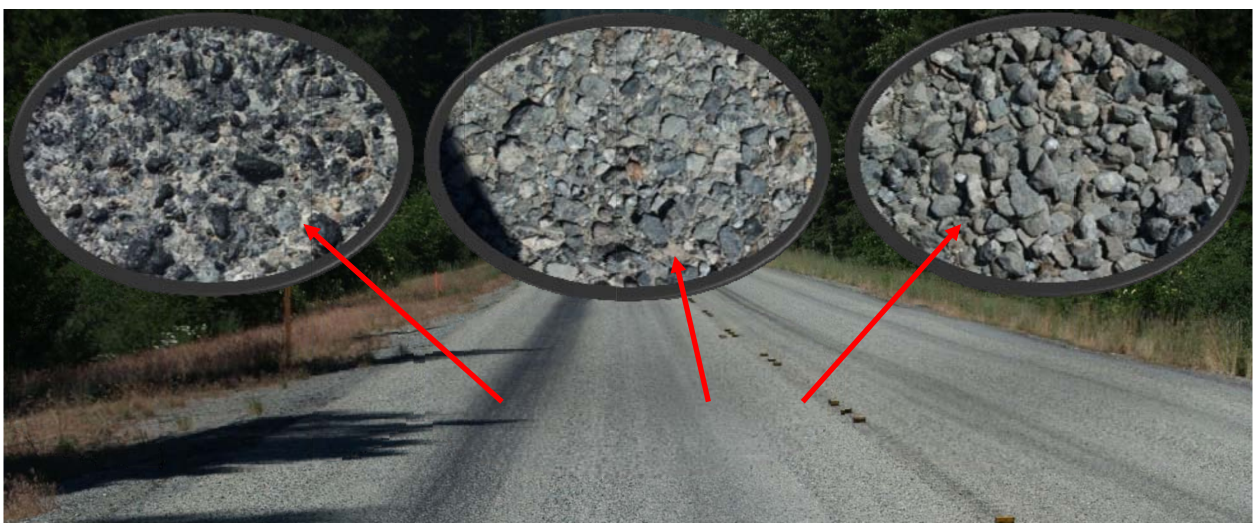

Figure 18 clearly illustrates why some design methods apply less binder in the wheelpaths. In some cases, the contractor is asked to apply sand material over badly flushed areas.

9.1.1 Comparison to design methods

The gradations for the aggregates used in the project are shown in Figures 19 and 20. The ½" US No.4 gradation is according to a gradation test. No test was available on the Us No.4-0 aggregate, therefore only the standard specification tolerance is shown for that aggregate type.

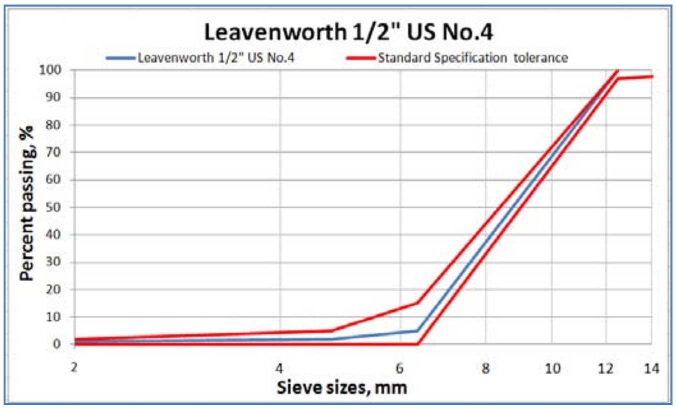

Figure 19 - Gradation test results for 1/2" US No. 4

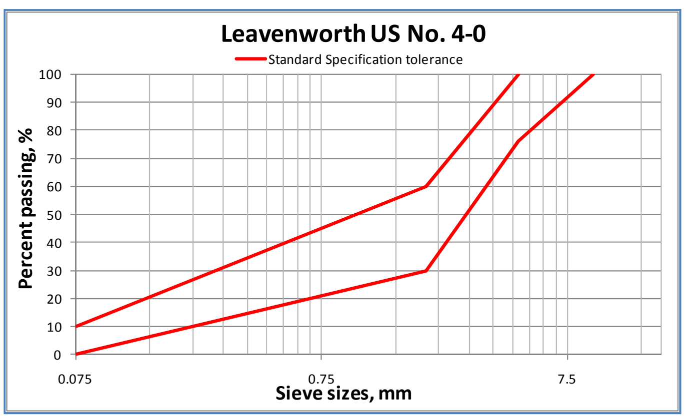

Figure 20 – Standard specification tolerances for US No. 4-0

The ½" US No.4 falls inside the standard specifications. The application rates for this project were compared to calculations using the McLeod Method and the Australian design method. The outcomes of the calculations are shown in Table 16 and Figure 21.

Table 16 - Applied and calculated application rates in Leavenworth

Item	Applied	Australia method	McLeod method	Standard Specs	
				min	max
Design binder application rate	2.54 l/m2	1.63 l/m2	1.38 l/m2	1.6 l/m2	2.5 l/m2
Aggregate application rate	21 kg/m2	14 kg/m2	16 kg/m2	11 kg/m2	19 kg/m2
Choke stone application rate	3.6 kg/m2	3 kg/m2	N/A	2.2 kg/m2	3.3 kg/m2

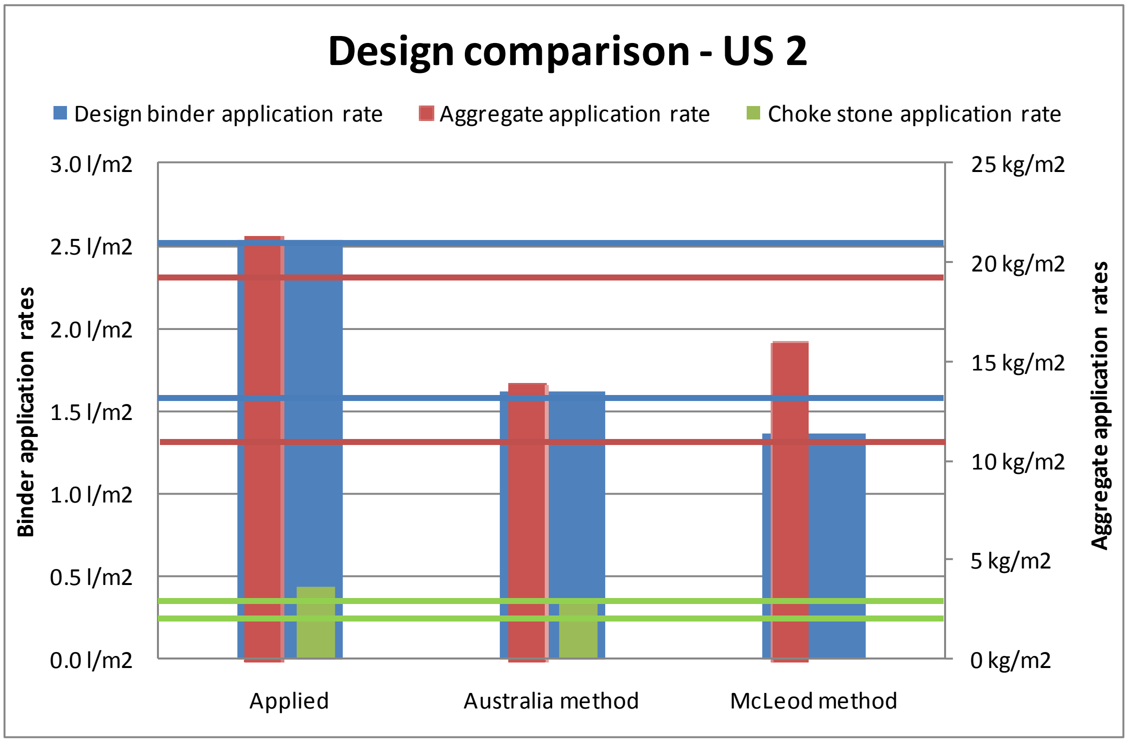

Figure 21 - Applied and calculated application rates in Leavenworth. The horizontal lines display WSDOT standard specification tolerances.

According to both design methods, the application rate of binder and aggregate were too high. Applied binder application rate is around 65% higher than the calculated rate of the design methods and the total aggregate application rate (first layer + choke layer) is about 50% higher. Applied rates exceed the standard specification tolerances, Australia and McLeod method rates fall within the standard specifications with the exception of the binder rate in the McLeod method which is about 0.3 l/m^2 lower than the minimum.

The McLeod method does not account for a choke stone application as it only calculates the binder and aggregate application rates based on a one stone thick aggregate layer.

9.1.2 Later look at the project

The road section was revisited on the 20th of July, 2009, 19 days after its completion. The section looked quite good, although the wheelpaths were bleeding in places as they had been on the day of construction. The bleeding had not been enough to justify an extra application of sand or fine aggregate on top of it. The chips had formed a good macrotexture surface and it is obvious that the choke stone is filling up the voids between the larger chips as seen in Figure 22.

Figure 22 - choke stone chips fills up the voids between the larger chips

Some corn rowing had occurred as can be seen in Figure 23.

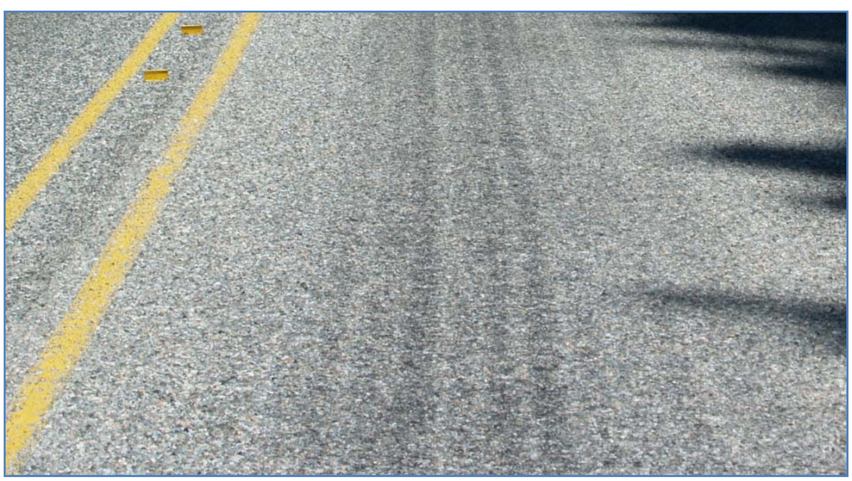

Figure 23 - Corn rowing due to uneven binder application

Corn rowing can occur if the spray bar height is not set to evenly distribute the binder. If the bar is set to low or to high it will result in longitudinal streaks. The strips with more binder on them will hold more aggregate than the rest of the roadway section, resulting in a longitudinal streaking texture of the finished surface. Other possible causes of corn rowing are wrong angle of nozzles, speed of the distributor, improper viscosity of emulsion or pump pressure (WSDOT, 2009 A).

9.2 R 829 - Eyjafjordur, North Iceland.

This project was visited on the 9th of July, 2009. It consisted of a 1.2 km long stretch of roadway close to Akureyri in North Iceland. This specific section is a part of a bigger chip seal project that includes about half of the chip seal overlays performed in ICERAs Northeastern region in the year 2009. The contractor, Malarvinnslan, was awarded the project based on the lowest bid of $318,000 out of 6 total bids. The bid was 22% lower than the engineers estimate (Vegagerdin, 2009). Weather conditions were ideal, rather warm, sunny and calm wind. The existing surface of the roadway was in good condition, little visible cracking and no other visible distress or faulting. The existing chip seal was constructed in 2005. Table 17 displays the major components of the project.

Table 17 - Project in Eyjafjordur, Iceland

R 829 - Eyjafjordur	
Date visited	7. 9. 2009
Contractor	Malarvinnslan
Area of total project	0.39 km^2
Area of studied section	9,100 m^2 (2.4% of totoal project)
Length of studied section	1.2 centerline km
Number of lanes	2
Weather condition, noon	
Temperature	12 °C
Wind speed	5 m/s
Humidity	70%
Cloud cover	Clear
Existing surface	BST
Surface condition	Good
Binder	SB 180 (95% asphalt, 5% rapes. oil)
Binder temperature	150 °C
Asphalt distributor	Etnyre. Model Cent II
Asphalt distribution rate	1.8 l/m^2
Residual asphalt content	100%
Aggregate gradation	11-16mm
Choke gradation	8-11mm
Chip spreader	Etnyre. Model Quad
Chip distribution rate	24 kg/m^2
Choke stone distributor	Etnyre
Choke distribution rate	3-4 kg/m^2
Rollers	
Make and model	Racing Hamm
Type	Pneumatic tire roller
Weight	N/A
Number of rollers	1

The type of chip sealing used was a method much like the choke stone method that is common in Washington State. Using choke stone is not common in Iceland although it has been tried in most regions and similar choke stone sections have performed well (Hjartarson, 2009). The binder used in this project was asphalt binder with rapeseed oil, SB 180, distributed by a computerized distributor at a rate of 1.8 l/m^2 which is the reference rate given in the tender documents.. The first layer of aggregate was 11-16mm gradation and the second one, the “choke stone”, was 8-11mm, see Figure 24.

Figure 24 - 11-16mm chips (left) and 8-11mm (right) used on the job

The chip spreader used was a self propelled Etnyre computerized spreader. There was only one spreader on the job resulting in a 1 hour time gap between the spreading of the first aggregate layer and the choke stone. This time gap will result in poorer adhesion between the choke stone and the binder. The contractor used 1 pneumatic tire roller to roll the aggregates. It is clear that rolling can’t be performed immediately after the spread of chips with only one roller on-site. This can result in poor adhesion between the aggregate and the binder if the binder starts to cure before initial rolling occurs. Rapeseed oil binder is rapid curing which makes it more important to roll the aggregates as soon as possible and apply the choke stone right after initial rolling. As stated before, this method is not common to use in Iceland and the standard specifications don’t mention this type of chip sealing.

Figure 25 illustrates that aggregate embedment of the first layer looks insufficient and when the second choke layer has been applied, no binder is visible.

Figure 25 - First layer applied (left), second layer, choke stone applied (right)

Residual asphalt content left on the roadway is not far off the Leavenworth project, 1.63 l/m^2 in Leavenworth compared to 1.8 l/m^2 in this project. Aggregate size is considerably higher in the Icelandic project which should result in a slightly higher binder application rate, although some bleeding did occur in the Leavenworth project. Both aggregate types seemed to be dusty considering the amount of dust that rose up from its application as seen in Figure 26. Despite this amount of visible dust, the fines in the aggregates did not exceed the 5% passing the 0.075mm sieve specified in Alverk95.

Figure 26 - dusty aggregate

9.2.1 Comparison to design methods

The chip seal consisted of two layers of aggregate, 11-16 mm and 8-11 mm. Gradation test result is shown in Figures 27 and 28.

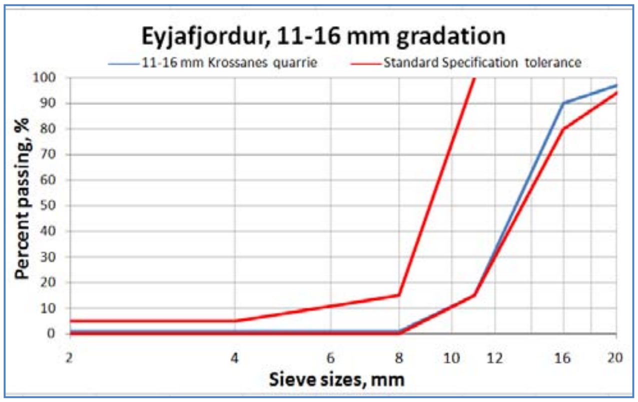

Figure 27 - 11-16 mm gradation test results

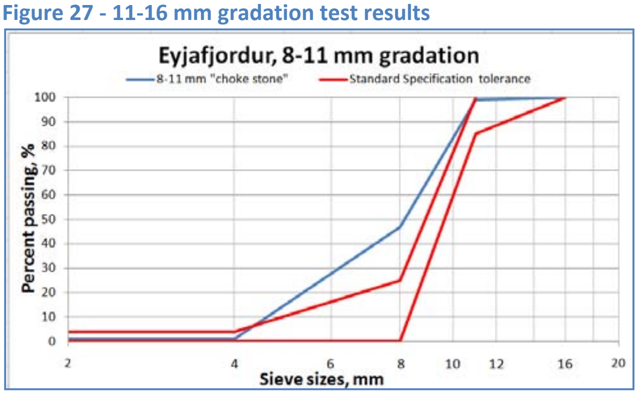

Figure 28 – 8-11 mm gradation test results

The 11-16mm aggregate gradation falls inside the specifications from Alverk95 but the 8-11mm “choke” aggregate does not because of the high percentage of stones passing the 8 mm sieve. The application rates for this project were compared to calculations using the McLeod Method and the Australian design method. The outcomes of those calculations are shown in Table 18 and Figure 29.

Table 18 - Applied and calculated application rates in Eyjafjordur

Item	Applied	Australia method	McLeod method	Standard Specs	
				min	max
Design binder application rate	1.80 l/m2	2.07 l/m2	1.66 l/m2	N/A	
Aggregate application rate	24 kg/m2	20 kg/m2	24 kg/m2	N/A	
Choke stone application rate	3.5 kg/m2	N/A	N/A	N/A	

* Rates are not available in standard specifications, rates are according to a guideline rate in tender documents

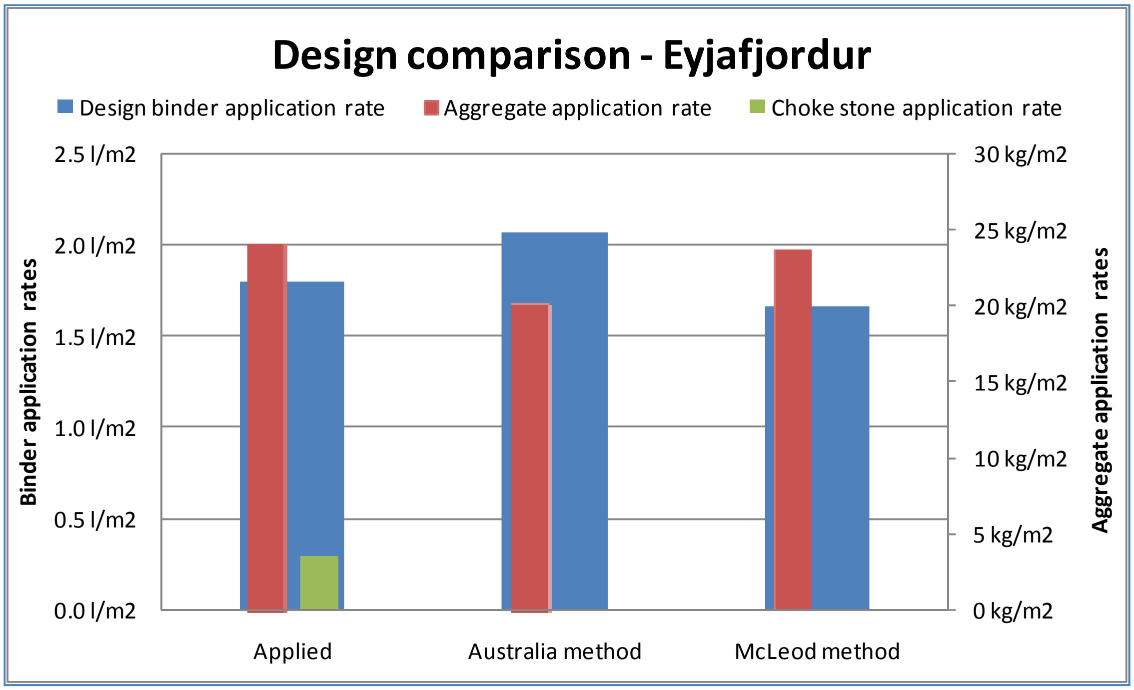

Figure 29 - Applied and calculated application rates in Eyjafjordur.

The actual application rates are not as far from the design methods as in the Leavenworth project. The Australia method gives a 20% higher binder rate and both methods give a lower total aggregate rate, Australia method 28% and McLeod 12%. It must be noted that the actual aggregate spread rates are merely a visual estimate as no on-site quantity measurements are done.

As stated before, the McLeod method does not account for a choke stone layer. The same applies for the Australian method. In the case of a conventional polymer modified binder it does not give an application rate for a scatter coat or a choke stone.

9.2.2 Later look at the project

The project was visited again on the 26th of July, 2009, 17 days after the section was chip sealed. The section looked quite good although Figure 30 shows that the aggregate chips have insufficient embedment in the binder. This might result in chip loss early on in the pavement life, especially during winter when the binder hardens and snow plows start scraping.

Figure 30 - Eyjafjordur finished surface

9.3 SR 262 south of Moses Lake

This chip seal project was done on a 39 km stretch on State Route 262, westwards from the junction of SR 262 and SR 17. This stretch was a part of a bigger project that included chip sealing parts of SR 155 and SR 243 combined into one contract. Table 19 describes major components and influencing factors of the project.

Table 19 - SR 262 project near Moses Lake, WA

SR262 - Moses Lake	
Date visited	7. 7. 2009
Contractor	Central Washington Asphalt
Area of total project	1.308 km^2
Area of studied section	380,230 m^2 (29% of totoal project)
Length of studied section	38.7 centerline km
Number of lanes	2
Weather condition, noon	
Temperature	22 °C
Wind speed	5 m/s
Humidity	31%
Cloud cover	Clear
Existing surface	BST
Surface condition	Good
Binder	CRS-2P
Binder temperature	65-75 °C
Asphalt distributor	Bear Cat CRC
Asphalt distribution rate	1.7 l/m^2
Residual asphalt content	~65%
Aggregate gradation	3/8" US no 10
Chip spreader	Bear Cat CRC
Chip distribution rate	13 kg/m^2
Rollers	
Make and model	ISR PT 125R
Type	Pneumatic tire roller
Weight	10 tons
Number of rollers	3

The project was visited on the 7th of July 2009. The contractor was Central Washington Asphalt who had the lower bid of $2,983,566 for the entire combined project described above. The bid was 9.5% under the engineering estimate (WSDOT, 2009 C).

The contractor finished this 39 km stretch in 4 days. The work started on Monday the 6th of July, one day prior to the visit. On that day the wind had presented some problems for the contractor as it exceeded 10 m/s for the majority of the day. As a result, the spray bar on the distributor had to be lowered to a single lap (see Figure 3) which means streaking or corn rowing is more likely to occur. Despite that, the section chip sealed that day looked promising and without any visible defects. The section had been swept and there was a lot of excess aggregate visible on the shoulder, see Figure 31.

Figure 31 - 1 day old chip seal. The section had been swept and looked good.

Weather conditions on the day of the visit were ideal, warm and sunny, low humidity and moderate wind. Existing surface of the roadway was an old BST in good condition, see Figure 32. No rutting was visible and the road showed little signs of other distresses, except for thermal cracks which were in most cases very fine. A few large transverse thermal cracks were identified that should have been sealed prior to the project. Those cracks are likely to quickly resurge through the chip seal, see Figure 33.

Figure 32 - Existing BST pavement was in good condition

Figure 33 - Transverse 1.5 inches wide unsealed thermal crack. The crack is visible through the chip seal applied the previous day

The binder used on this project was a CRS-2P which is the most common binder used in Washington State. The binder was distributed with one computerized distributor at an average rate of 1.7 l/m^2 and a temperature of around 70^oC, both of which fall inside WSDOT standard specifications for this type of chip seal. According to the shot notes from the project, which estimates the application rate for each shot the distributor makes, the binder application rate varied from 1.5l/m2 to 1.85l/m2 for the total job section. The aggregate gradation type used was 3/8 US No.10 and was applied with a computerized Bearcat chip spreader at a rate of 13 kg/m^2 according to the aggregate distribution notes. The aggregate was screened on-site because it was too dusty according to standard specifications, the percentage of particles passing the nr.200 sieve was too high. Three 10 ton pneumatic tire rollers were used for rolling. The rollers made 2-4 complete coverages of the roadway, which is satisfactory according to standard specifications that require a minimum of 2 complete coverages. When the chip spreader was not spreading, e.g. when the binder distributor is filled up or when the spreader is waiting for a dump truck, the roller operators also stopped rolling and waited for the spreader to continue. The rollers should never stop because it's not possible to do too much rolling on a chip seal with pneumatic tire rollers. More rolling ensures better orientation of the chips and more interlock between them. The roller operators did not seem to be following a specific rolling pattern and at times the rollers were far apart from the spreader.

When observing the broomed section from the previous day it is evident that the biggest chips are less likely to stick to the binder and therefore the majority of the chips that covers the roadway are the smaller ones, especially in the wheelpaths where car tires whip off the largest chips and settle the smaller ones (Moomaw, 2009), see figure 34.

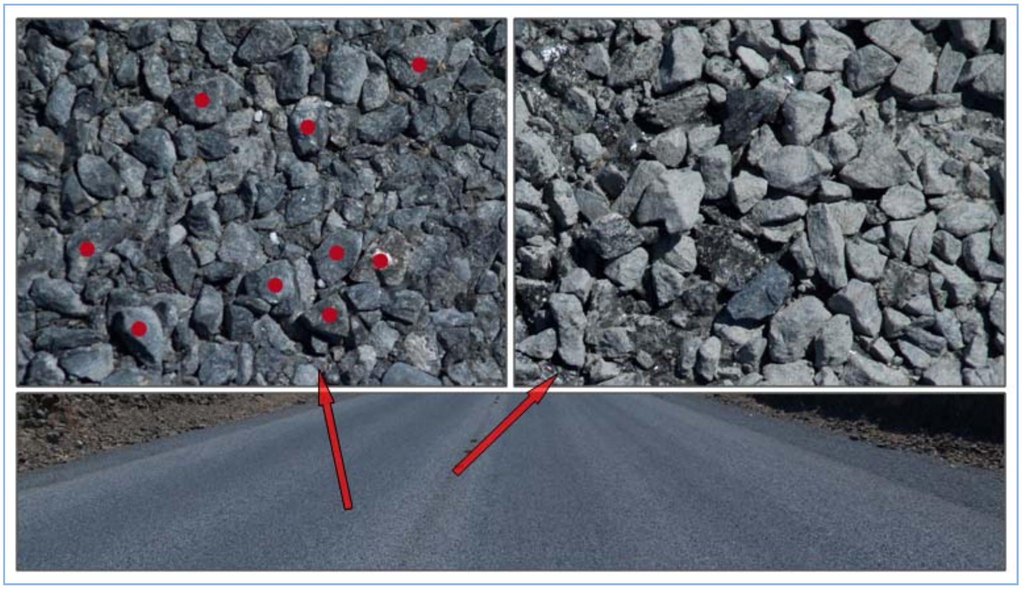

Figure 34 – A day old chip seal that has been swept. Chip sizes clearly differ from the wheelpath to the middle joint. The biggest chips have been whipped off by traffic in the wheelpaths. The images above are roughly the same scale.

Figure 34 demonstrates that the non-wheelpath areas will experience a lot more aggregate loss as the chips are not embedded well enough before the binder cures. This aggregate loss is especially evident on roadways where snowplows are commonly used, as the snowplows will whip off the chips in the non-wheelpath areas. To prevent this excessive aggregate loss it is important that rollers use their "downtime" to roll extra passes over those areas. Operators of other construction equipment like dump trucks and binder tank trucks should be asked to drive outside the wheelpaths to help embedding the chips into the binder, see Figure 35.

Figure 35 - Dump truck operators should try to drive on the non-wheelpath areas to ensure better orientation and embedment of chips in those areas.

9.3.1 Comparison to design methods

This chip seal consisted of a single layer of CRS-2P emulsion and one application of 3/8" US No.10 aggregate. Several gradation tests were done for this project and the average gradation is shown in Figure 36. The gradation is inside WDOT's Standard Specification tolerances.

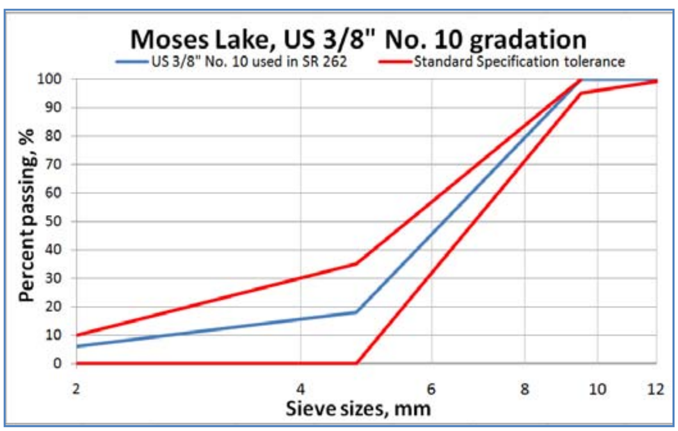

Figure 36 - Gradation test results for SR 262

The application rates for this project were compared to calculations using the McLeod Method and the Australian design method. The outcomes of those calculations are shown in Table 20 and Figure 37.

Table 20 - Applied and calculated application rates for Moses Lake

Item	Applied	Australia method	McLeod method	Standard Specs	
				min	max
Design binder application rate	1.70 l/m2	1.53 l/m2	1.18 l/m2	0.90 l/m2	1.80 l/m2
Aggregate application rate	13 kg/m2	9 kg/m2	11 kg/m2	10 kg/m2	16 kg/m2
Choke stone application rate	N/A	N/A	N/A		

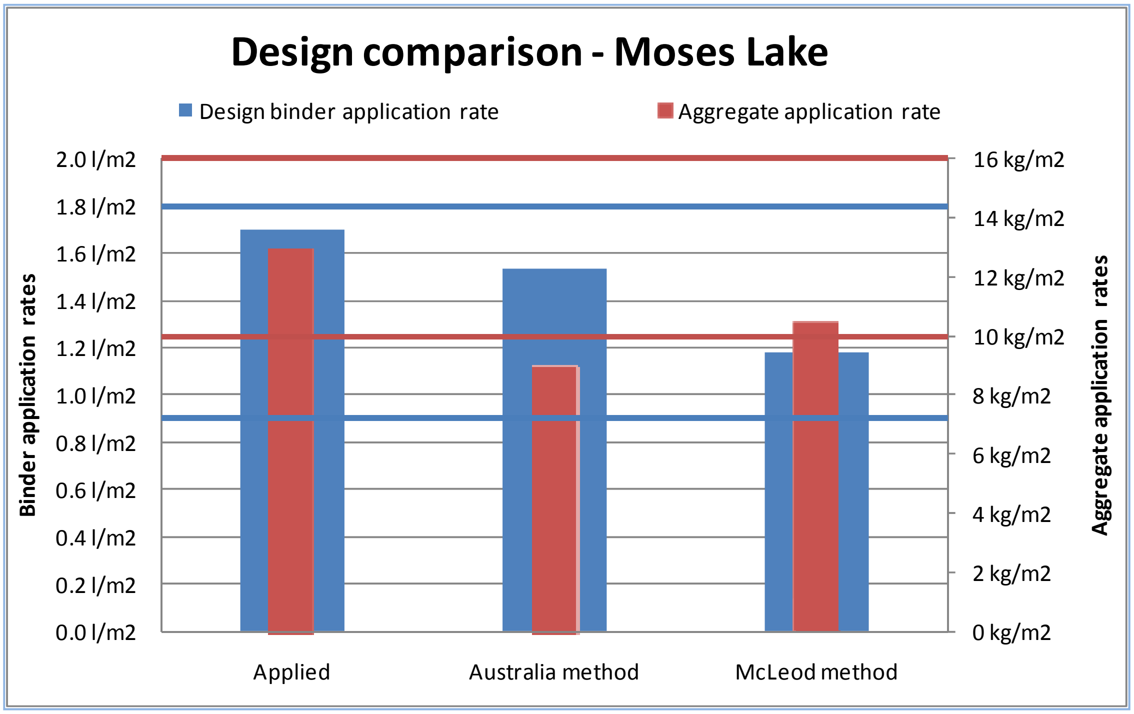

Figure 37 - Applied and calculated application rates for Moses Lake. The horizontal lines display the standard specification tolerances.

This project shows a similar trend as the Leavenworth project. The applied rates are higher than the rates calculated by the design methods although the difference is not as great in this case. The binder rate calculated by the Australian and McLeod method are 10% and 30% lower than the applied rates, respectively. The aggregate application rate calculated by the Australian method is almost half of the applied rate and the McLeod method gives a 15% lower rate than the actual applied rate.

9.3.2 Later look at the project

The project was visited again on the 20th of July, 2009, two weeks after the first visit and 11 days after the chip sealing was finished. The section looked quite good. Some corn rowing was visible on the section performed during the day of the first visit and the sections performed the two following days, see Figure38.

Figure 38 - Project visit 7.7.2009, streaks in the asphalt binder will cause corn rowing

One intersection in the project was paved with HMA, all other intersections were chip sealed. Intersections sustain stop and go and turning movements and are therefore more susceptible to bleeding and chip loss than other parts of the roadway. Applying a correct and even layer of binder is more challenging than on straight section. Figure 39 shows an intersection being chip sealed at the first visit as well as a picture of it after two weeks of operation. Picture on the left shows how difficult it can be to get an even application of binder, overlaps of the application shots are clearly visible. Those overlaps are a definite source of bleeding. The middle picture shows that the adjacent road lane was finished first although the binder had already been applied on the intersection. This resulted in too much time passing between the application of the binder and the chips so the binder started to cure before the aggregate application. Picture on the right shows the result. There is significant bleeding and it’s more evident on the side where vehicles may have to stop for traffic.

Figure 39 – Chip sealing an intersection

The surface of the main roadway looked good. The chips had formed a tight macrosurface texture, the binder had good elasticity and the adhesion between the binder and the chips was strong based on a number of tries to dislodge a chip, see Figure 40.

Figure 40 - The chips had good embedment and the binder elasticity was intact

9.4 R 33 - Gaulverjabæjarvegur, South Iceland

This project was visited on 14th of July, 2009. The job consisted of resealing a 3 km stretch of roadway in southern part of Iceland. It was a part of a bigger project where all chip sealing projects in southwestern part of Iceland are put together and opened up for bid. The contractor Ræktunarsamband Flóa og Skeiða, was awarded the project based on the lowest bid of $400,000 out of 4 total bids. The bid was 8% lower than the engineers estimate (Vegagerdin, 2009). The weather conditions for chip sealing were poor, partly cloudy, 13°C and strong breeze of 12m/s. The existing surface had a very rough texture, probably due to insufficient aggregate embedment resulting in aggregate loss, see Figure 41. The aggregate on the existing surface seemed to be round and porous which can also contribute to chip loss.

Figure 41 - Rough textured existing surface

The existing surface of the roadway had been chip sealed in 2002 with the same type of aggregate used in this project.

Table21 lists the major components of the project.

Table 21 – Gaulverjabær R 829, southwest Iceland

R 33 - Gaulverjabær	
Date visited	7. 14. 2009
Contractor	Ræktunarsamb. Flóa og Skeiða
Area of total project	0.4 km^2
Area of studied section	19,100 m^2 (4.8% of totoal project)
Length of studied section	3.0 centerline km
Number of lanes	2
Weather condition, noon	
Temperature	13 ^oC
Wind speed	12 m/s
Humidity	60%
Cloud cover	Partly cloudy
Existing surface	BST
Surface condition	Porous and oxidized
Binder	SB 180 (95% asphalt, 5% rapes. oil)
Binder temperature	150 ^oC
Asphalt distributor	N/A
Asphalt distribution rate	1.7 l/m^2
Residual asphalt content	100%
Aggregate gradation	8-16mm
Chip spreader	N/A
Chip distribution rate	24 kg/m^2
Rollers	
Make and model	N/A
Type	Pneumatic tire roller
Weight	N/A
Number of rollers	1

This was a typical single layer chip seal commonly used in Iceland. The aggregate gradation was 8-16mm, which is the most common gradation for resealing in Iceland. The binder was spread with a computerized distributor at a rate of 1.7l/m^2 and 150^oC. The binder used was SB180, which consists of 95% asphalt and 5% rapeseed oil. Amin, an adhesive modifying agent, was added in the mix in the amount of 0.8% of the weight of the binder. The strong breeze clearly affected the application of the binder and therefore exceeded the standard specifications, see Figure 42.

Figure 42 - The strong breeze is affecting the binder distribution

To perform a chip seal under these conditions is controversial. Mitigating measures such as adjusting the spray bar height or shielding it for the wind should have been taken in this case. A self propelled chip spreader was used to spread the aggregate at a rate of 24 kg/m^2. The aggregate spread rate is a visual estimate by the chip spreader operator. The aggregate used seemed to be similar to the existing aggregate on the roadway, it was fairly rounded and porous and a little dusty and gradation tests showed that the percent passing the No. 200 sieve (0.075 mm) was 1.8%, see Figure 43.

Figure 43 - Fairly round aggregate and insufficient embedment

Figure 43 shows that the aggregate does not seem to have sufficient embedment which should be around 50-60%.

Only one pneumatic tire roller was used for rolling. The roller completed 4-5 coverages of the roadway. Although the roller never stopped rolling during the visit it is clear that having two or three rollers would guarantee better initial rolling right after the chips have been spread. It is important to start the aggregate orientation process as soon as the chips have been spread. Doing so with one roller is impossible in a project that covers many kilometers.

9.4.1 Comparison to design methods

The chip seal consisted of a single layer of 8-16 mm aggregate. Gradation tests were performed for the aggregate and the results are shown in Figure 44.

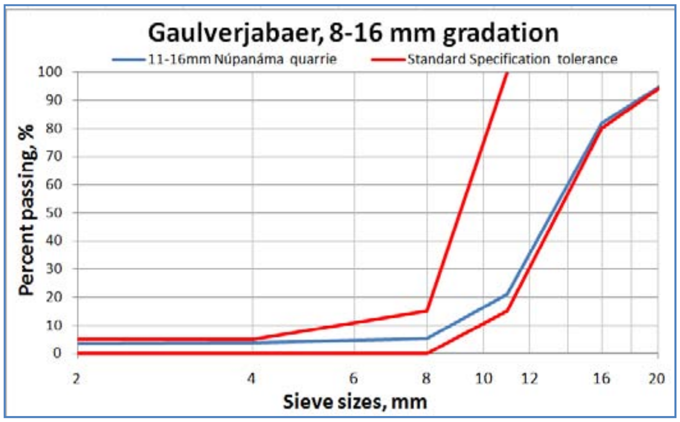

Figure 44 - Gradation test results of 11-16mm aggregate used in the R 829 project.

The 8-16mm aggregate gradation falls inside the specifications from Alverk95. The application rates for this project were compared to calculations using the McLeod Method and the Australian design method. The outcome of those calculations are shown in Table 22 and Figure 45.

Table 22 - Applied and calculated application rates in R 829

Item	Applied	Australia method	McLeod method	Standard Specs	
				min	max
Design binder application rate	1.70 l/m2	2.50 l/m2	1.93 l/m2	1.8 l/m2*	
Aggregate application rate	24 kg/m2	20 kg/m2	22 kg/m2	24 kg/m2*	

* Rates are not available in standard specifications, rates are according to a guideline rate in tender documents

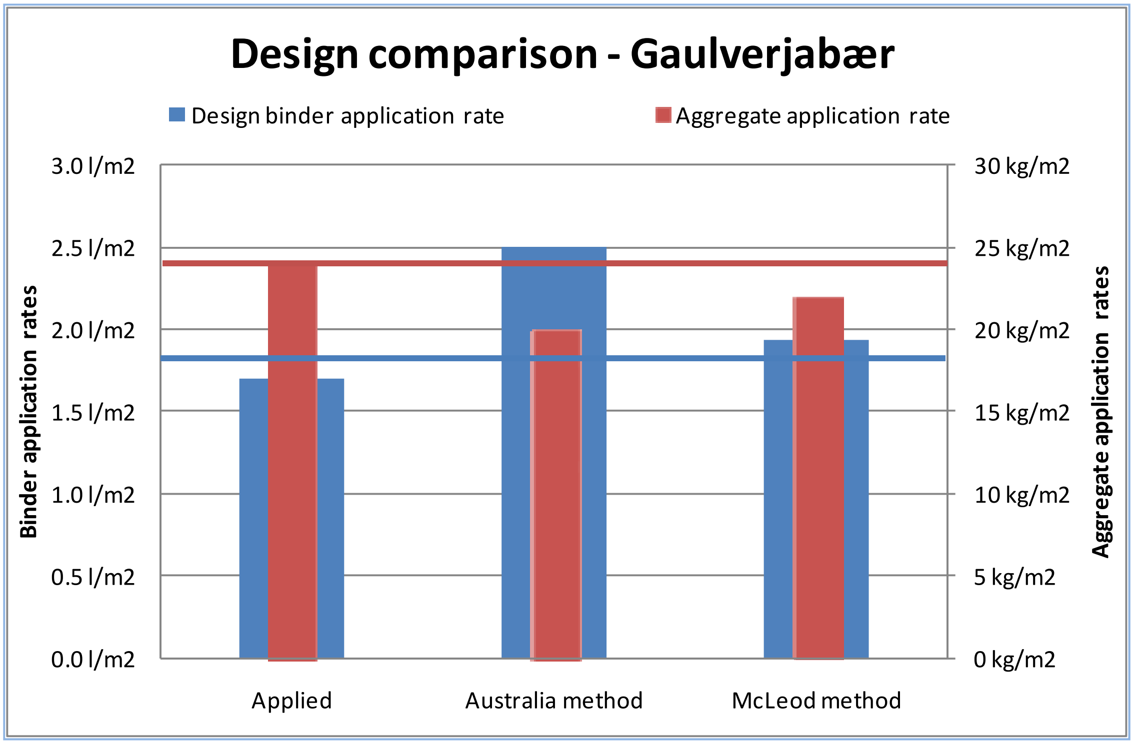

Figure 45 - Applied and calculated application rates in R 829. The horizontal lines display the guideline rates from tender documents.

The outcomes of the calculated designs both indicate higher binder application rates and lower aggregate application rates. The Australian method gives a 55% higher binder rate and the McLeod method 20% higher compared to the applied binder rate. Both design methods give an aggregate application rate of around 20kg/m^2 which is about 20% lower than the application rate given in the tender documents. As in the Eyjafjordur project, the aggregate application rate is merely a visual estimate and can´t be confirmed because of lack of quantity data gathered on-site.

Depending on how deep the existing surface depth was, the Australian method might have advised another surface treatment for this project. A 0.4 l/m^2 was added to the binder application rate as the surface texture allowance based on an estimated texture depth of 1.4-1.8mm, see Table 11 on page 44 and calculation sheet in Appendix 3. If the surface texture exceeds 1.8mm, the Australian design method suggests correcting the rough surface with an alternative treatment such as smaller size seal prior to chip sealing with larger aggregates.

Figure 46 shows the existing surface when the asphalt binder has been applied to it. A uniform chip embedment of aggregates is hard to attain on such a rough surface.

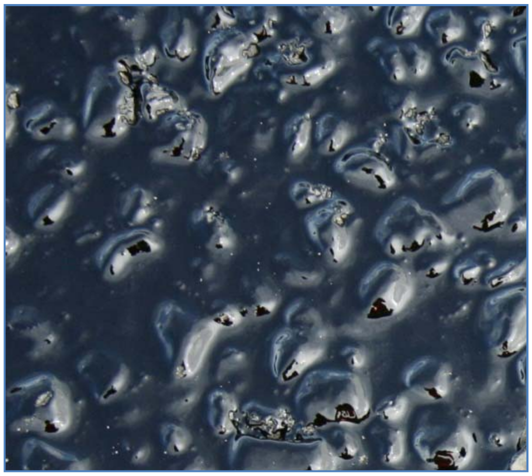

Figure 46 - Rough existing surface showing through the binder

9.4.2 Later look at the project

The project was revisited on August 5th, 2009, 3 weeks after the project was completed. The existing surface looked really rough and aggregate embedment seems to be insufficient.

Figure 47 – Gaulverjabaer R 829 finished surface

10 Conclusions

Following are the main conclusions that can be drawn from the literature review, case studies and interviews conducted for this paper.

10.1 Materials

- Quality aggregate is seldom a problem in Iceland or Washington State. Both regions are abundant with durable and abrasive resistant aggregates.
- Most commonly used gradation types in Iceland are more uniformly graded and larger than the ones used in Washington State.
- Some regions in Iceland are using gradations not mentioned in standard specifications due to cost.
- Rapeseed oil binder has been used in Iceland since 2006 with fairly good results:
    - Rapeseed oil asphalt has virtually eliminated compensation claims on ICERA due to bleeding surfaces.
    - No volatile chemicals evaporate from the binder.
    - High asphalt content (95%) decreases hauling cost.
    - Has proven to be sensitive to dust.
    - Contractors complain about difficult handling.
    - Rapeseed oil is expensive and it cancels out the savings from hauling cost.
- Washington State uses asphalt emulsion binders:
    - WSDOT has long experience with emulsion binders.
    - No volatile chemicals evaporate from the binder.
    - Lower application temperatures means less energy consumption and lesser risk of burning injuries.
    - Emulsions are less sensitive to climatic factors like cold weather and light rain compared to cutbacks or rapeseed oil binder.
    - Higher hauling costs due to low residual asphalt content of binder.
    - High ambient and surface temperature can cause adhesion failures between the binder and aggregate.

10.2 Standard specifications

- ICERAs standard specifications ALVERK95:
    - Standards have not been updated since 1995.
    - Standards are out of date and important parts relevant to modern chip seals are missing.
    - Structure of the standards hinders updating for specific sections.
- WSDOTs standard specifications
    - Updated every 2 years.
    - More detailed than the Icelandic standards.

- Special revaluation efforts have been made past 4 years for chip sealing.

10.3 Designs

- Both agencies use empirical design methods to estimate the binder and aggregate application rates.
- The actual application rates are then adjusted according to conditions for each project.
- Neither agency performs necessary tests required to calculate the application rates according to the most widespread design methods, for example the McLeod method and the Australian design method. These design methods require tests for estimating the existing surface with a sand patch method and aggregate tests for evaluating the average least dimension (ALD) of aggregates.

10.4 Contracting

- The number of contractors that bid on chip sealing projects on a regular basis is higher in Iceland than in Washington State.
- Qualification requirements of contractors seem to be tougher in Washington which might explain fewer contractors. In Washington, contractors are prequalified to bid on a project but in Iceland the qualification process is done on a project to project basis.
- Washington contractors are paid based on volumes of materials used, binder and aggregate.
    - The downside of paying by the volume of material is that the agency bares the risk of excess volumes used.
- In Iceland payments are made based on square meters.
    - Paying by the area gives the contractor a motive to use the minimum amount of materials.
- Contractors in both regions are very rarely held totally liable if a chip seal job turns out to be a failure.
- According to the case studies, the Icelandic projects were more expensive in dollars per square meter.
- Mobilization, preparation and traffic control costs are negligible in Iceland compared to the Washington prices but other components are significantly more expensive.

10.5 Construction practices – case studies

- Choked seals have proven to perform well in both Iceland and Washington State although their designs are different.
- Sweeping prior to binder application is rarely done in Iceland but is a standard practice in Washington.

- One roller is the norm to use in Iceland compared to three in Washington. One roller can hardly attain sufficient rolling according to specifications.
- Inspection practices are very much unlike in the two regions:
    - Inspection in Iceland is very poor. In some cases, a chip seal project is finished without any on-site inspecting by the agency. With the current level of inspection, it is impossible for the agency to enforce its specifications. The contractor liability is virtually eliminated when little or no inspection is done and no quantity measurements or logs are available.
    - Inspection efforts in Washington State are high with three inspectors on-site during the application period logging the application rates and monitoring the overall process.
- Dusty aggregates were apparent in Eyjafjordur project and SR 262.
    - Specifications allow up to 5% passing the 0.075 mm sieve in Icelandic gradations. Most agencies specify a maximum 1-2%.
    - Specifications for the US No.4-0 gradation, or choke stone, allow up to 10% passing the 0.075 mm sieve. Most agencies specify a maximum 1-2%.
- Rough existing surface like in the Gaulverjabaer project could cause problems. Mitigating methods should be considered in such cases.
- Wind affected binder application in the Gaulverjabaer project, causing uneven spread of binder.
- One hour gap between applications of the first aggregate layer and the choke layer in the Eyjafjordur project could cause adhesion problems.
- Choke stone application was at times to far behind the first aggregate layer in the SR 262 project.
- In both Washington projects, chip spreaders were sometimes too far behind the asphalt distributor.
- Corn rowing was visible in both Washington projects, indicating an uneven binder application.
- Some bleeding was visible in both Washington projects, especially on US 2.

- For the Icelandic projects, specified binder application rates were lower than the calculated rates from the design methods. Aggregate rates that were specified were in both cases a little higher than the calculated ones. No reliable quantity measures are done on-site so the actual application rates are unreliable as they are merely visual estimates.

- For the Washington projects, actual application rates for binder and aggregates are in all cases higher than the calculated rates from the design methods.

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Appendix 1

Standard specifications

In this section, standard specifications regarding chip seal construction from Icelandic Road Administration (ICERA) and Washington State Department of Transportation (WSDOT) will be compared. WSDOT Standard Specifications version 2008 will be used as well as ICERA's standard called Alverk 95. The order of the discussion will be according to the order of segments in WSDOT Standard Specifications.

Equipment

Asphalt emulsion distributor

WSDOT	ICERA
Temperature measuring device in distributor tank	Temperature measuring device in distributor tank
Temperature measuring device for emulsion applied on roadway	Emulsion tank shall be capable of distributing variable amount of emulsion over the spray bar
A tachometer to accurately control asphalt application	Emulsion tank shall be capable of evenly distributing the pressure over the entire spray bar
Adjustable spray bar with pressure pump and gauge	Volume control gauge
Uniform spray from each of the nozzles	
Volume control gauge	

Rollers

WSDOT	ICERA
Self propelled pneumatic tire rollers for seal coat	8-12 tonnes self propelled pneumatic tire rollers
Self propelled pneumatic tire rollers and smooth wheeled rollers for new construction	6-8 tonnes self propelled vibrating pneumatic tire rollers.
Rollers shall not weigh less than 12 tons	6-8 tonnes self propelled vibrating rollers with steel drum on one axle and a rubber drum or wheels on the other axle

	Steel drum roller cannot be used when overlaying on existing pavement. Vibrating with steel drum is not allowed.

Chip spreader

WSDOT	ICERA
Self propelled, supported on at least four pneumatic tires Approved device for accurately spreading aggregate uniformly over roadway surface Operator shall be allowed to adjust the spreading width of aggregates in 6 inch increments without stopping machine	N/A (although not in Alverk, all job specifications specify a self propelled chip spreader)

Brooms

WSDOT	ICERA
Capable of controlling vertical pressure	N/A

Construction

Preparation of sub-base

WSDOT	ICERA
Immediately before the prime coat of asphalt emulsion is applied, the Roadway surface shall be in the following condition: firm and unyielding, damp, free from irregularities and material segregation, and true to line, grade, and cross-section.	Sub-base shall be well compacted with no loose material at the surface, damp and free of stones larger than 25mm.
No traffic is allowed until aggregate has been applied	No traffic is allowed until aggregate has been applied

Seal coats

WSDOT	ICERA
Existing BST shall be swept with a power broom and free from dirt or other foreign	N/A

matter	
Repair of existing pavement shall be done according to standards	Repair of existing pavement shall be done according to standards preferably 1 at least 1 month before seal coating

Fog seal

WSDOT	**ICERA**
Existing BST shall be free from dirt or other foreign matter The existing pavement shall be dry before applying fog seal	N/A

Application of asphalt emulsion

WSDOT	**ICERA**
Longitudinal joints will be allowed at only the centerline of the Roadway, the center of the driving lanes, or the edge of the driving lanes.	Longitudinal joints are only allowed at the centerline of the roadway.
Contractor shall provide a minimum 1,000-foot test strip when beginning a BST section.	Transverse joints shall be done with building paper to avoid gaps and ridges when waiting time exceeds 3 minutes or ADT>500
Transverse joints shall be done with building paper to avoid gaps and ridges	Emulsion shall be covered with aggregate within 1 minute from the time of application
Emulsion shall be covered with aggregate within 1 minute from the time of application	Before spraying emulsion, nozzle accuracy shall be tested according to standards. Tests shall done 2 times each summer
Asphalt emulsion shall be spread toward the source of aggregate to avoid injury to the freshly treated surface.	If 2 layers are used road should be open for traffic on the first layer as soon as possible. Second layer is applied when sufficient curing of first layer is reached
	Newly placed aggregates shall be swept prior to the application of second layer
CSS-1 and CSS-1h emulsified asphalt may be diluted at a rate of one part water to one part emulsified asphalt unless otherwise directed by the Project Engineer.	When binder is applied to a roadway with ADT>1,500, up to 25% less emulsion should be applied in wheelpaths

Fog sealing shall be applied no sooner than 3-days, but no later than 14-days after new construction or seal coat.

If required, newly placed aggregates shall be swept prior to the fog seal application.

Application of aggregate

WSDOT	ICERA
All aggregate stockpiles shall be watered down to provide aggregates that are uniformly damp at the time of placement on the Roadway.	Aggregates shall be as dry as possible when applied
A 20cm strip of asphalt emulsion shall be left exposed along the longitudinal joint to form a lap for the succeeding applications of asphalt emulsion.	A 5-10cm strip of asphalt emulsion shall be left exposed along the longitudinal joint to form a lap for the succeeding applications of asphalt emulsion.
A minimum of 3 pneumatic tired rollers providing a minimum of 2 complete coverages to the Roadway immediately behind the spreading equipment for the coarse aggregate shall be required.	When 2 layers of aggregates or applied on sub-base, the first layer should be rolled once and the second layer twice.
The maximum rate of roller travel shall be limited to 8 mph.	Shoulders shall be rolled with one extra round
Choke aggregates shall be applied immediately following the initial rolling of the coarse aggregate	The completed surface shall be allowed to cure and then broomed as soon as practical.
A minimum of 1 pass with a pneumatic roller shall be made across the entire width of the applied choke aggregate.	
The completed surface shall be allowed to cure and then broomed as soon as practical.	

Progress of work

WSDOT	ICERA
The Contractor shall organize the Work so that no longitudinal joints shall remain open overnight.	N/A

Unfavorable weather

WSDOT

Asphalt emulsion shall not be applied to a wet Roadway.

Subject to the determination of the Project Engineer, asphalt emulsion shall not be applied during rainfall, sand or dust storms, or before any imminent storms that might damage the construction.

The Roadway surface temperature shall be at least 13^{o}C.

The air temperature shall be at least 16^{o}C and rising.

The air temperature shall be not less than 21^{o}C when falling

Wind shall be less than 4.5m/s as estimated by the Project Engineer.

The surface temperature shall be not more than 60^{o}C.

No asphalt emulsion shall be applied which cannot be covered 1-hour before darkness.

Construction of bituminous surface treatments on any traveled way shall not be carried out before May 1 or after August 31 of any year except upon written order of the Project Engineer.

ICERA

Asphalt emulsion shall not be applied to a wet Roadway.

Air temperature shall be at least 5^{o}C and rising

Roadway surface temperature shall be at least 3^{0}C and rising

Emulsion shall not be applied if wind is strong enough to uneven its distribution or if the wind cools the emulsion too much

Contractor shall record temperature, wind speed and precipitation at least 3 times per day

Measurements, contract payments

WSDOT

Asphalt emulsion of the grade or grades specified will be measured by the ton

Asphalt for fog seal will be measured by the ton, before dilution,

Aggregate from stockpile for BST will be measured by the cubic yard in trucks at the point of delivery on the Roadway.

ICERA

Payment is based on designed area of paved road surface in m^2

Furnishing and placing crushed aggregate will be measured by the cubic yard in trucks at the point of delivery on the Roadway, or by the ton

Appendix 2

CONTRACT 7733
NC REGION 2009 STAGE 2
CRS-2P SHOT NOTES

23.43

Item #3 Inspector--

SHOT # / DATE	BEG. GAL. / BEG. MP	END GAL. / END MP	SECTION LENGTH	GROUP WIDTH	SIDE	HOT GALLONS	TEMP. CORR.	COLD GALLONS	SQUARE YARDS	YIELD G/SY	CERT. # / SAMPLE #
1	3500	1100		1	LT	2400	.97250	1945		.35	138
7/7/09	22.76	23.43	3800	16		170			6756		4
1	1100	50		1	RT	1050	.972500	1021		.38	138
7/7	22.76	23.03	1500	16					2667		
2	3800	2300		1		1500	.97500	1463		.39	138
7/7	23.03	23.43	2212	16	RT				3755		
2	2300	700		1	LT	1500	.97500	1463		.39	138
7/7	23.43	23.83	2212	16					3755		
2	700	100		1	RT	[illegible]	.97500	585		.34	138
7/7	23.43	23.61	950	16					1689		
3	4100	3350		1		750		729		.35	127
7/7	23.61	23.83	1162	16	RT		.97250		2066		
3	3250	1850		1		1400		1362		.37	137
7/7	24.22	23.83	2059	16	RT		.97250		3660		
3	1500			1		1350		1313			137
7/2	24.22	23.83	2059	16	LT		.97250		3660	.36	
3	500	Ø		1		500		486		.35	127
7/7	16.05	15.85	1050	12	RT		.97250		1400		
4	3300	100		1	RT	3200	.97500	3120		.39	137
7/7	15.80	14.85	5602	13					8092		
5	3700	Ø			LT	3700	.97250	3598		.37	135
7/7	16.05	14.65	7370	12					9827		5
6	3500					3500	.97500	3413		.38	135
7/7	14.85	13.68	6212	13	RT				8973		

Section	Group		Cold Gal	SY		
1	1	Totals =	20,498	56,300	.37	Avg Yield

(Length)(Width) /Cold Gals = Application Yield
9

S
M
S

Sample of a WSDOT shot note logging emulsion binder application

Contract 7733 Contractor CENTRAL WASH. ASPHALT Sheet 2 of 4

Item No. 8 Material 3/8 To No 10 (Aggr. Source-) Date 7-13-09

Load	Truck #	Time	MP	MP	Lt./Rt.	Width	S.Y.	Yield	Group	Notes
1	201	9:48	2.33	2.41	RT	18			2	12 (126)
2	"	10:02	1.88	1.93	LT	16				4
3	8	10:04	1.93	2.05	LT	16				15 (19)
4	209	10:06	2.05	2.18	LT	16				16 (35)
5	G3	10:08	2.18	2.37	LT	16	4599	29.4		15 (50)
6	250	10:11	2.37	2.45	LT	16				21 (71)
7	205	10:13	2.45	2.57	LT	16'				16 (87)
8	251	10:15	2.57	2.75	LT	16'				21 (108)
9	G13	10:22	2.75	2.80	LT	16'	8636	36.9		10 (118)
10	"	10:29	2.41	2.47	RT	16'				5
11	G10	10:31	2.47	2.61	RT	16'				15
12	G9	10:34	2.61	2.72	RT	16				15 (35)
13	253	10:35	2.72	2.86	RT	16'				21 (56)
14	252	10:39	2.86	3.05	RT	16'	6007	34.6	2	21 (77)
15	201	10:46	3.05	3.17	RT	16'			2	16 (93)
16	8	10:50	3.17	3.35	RT	16'	8823	33.1	3	15 (108)
17	220	10:57	2.80	2.93	LT	16'			2	16
18	205	11:00	2.93	3.05	LT	16'			2	16 (32)
19	8	11:03	3.05	3.21	LT	16'			2	15 (47)
20	209	11:05	3.21	3.30	LT	16'			3	16 (63)
21	G3	11:07	3.30	3.42	LT	16'				15 (78)
22	251	11:10	3.42	3.58	LT	16'				21 (99)
23	G10	11:15	3.58	3.62	LT	16'	7697	36.5		5 (104)
24	"	11:39	3.35	3.44	RT	16'				10
25	G13	11:42	3.44	3.54	RT	16'				15 (25)
26	G9	11:45	3.54	3.65	RT	16'				15 (40)
27	253	11:47	3.65	3.78	RT	16'				15 (55) 0 SW
28	201	11:50	3.78	RA 3.75 RT 3.84	RT	16'				16 RA 3.75 RT
29	252	12:09	3.84	3.98	RT	16'				21
30	250	12:17	3.98	4.16	RT	16				21
31	220	12:21	4.16	4.18	RT	16'				4
32	"	12:30	3.62	3.71	LT	16'				12
33	8	12:32	3.71	3.84	LT	16				15 (27)
34	209	12:42	3.84	3.86	LT	16'				16 (43) RA 3.80 LT
35	205	12:48	3.86	4.02	LT	16'			3	16 (59)

# Loads x CY per load x(______) / 9 = #/SY Yield
Length(Ft) x Width (Ft)

8 SW 20
235 ALL 44
317 TOTAL 64

Number of loads __________ X ____ C.Y. per load = ______________

FIELD

Received By: ____________________

Verified By: ____________________

DAILY TOTAL ______________

OFFICE

Computed By: ____________________

Checked By: ____________________

IQT NO. ______________

Sample of a WSDOT log of aggregate application

Appendix 3

US 2 – McLeod method

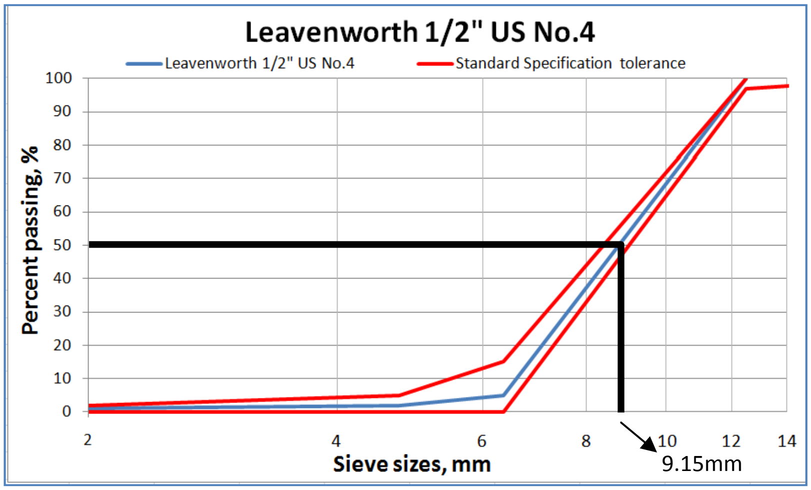
Median particle size	M	9.15mm
Flakiness index	FI	20.0%
Average least dimension	H	6.68mm
Loose unit weight	W	1,600 kg/m3
Bulk specific gravity	G	2.71
Voids in loose aggregate	V	0.409
Aggregate absorption	A	<2%
Aggregate absorption factor	A_F	0.00 l/m2
Traffic volume	ADT	>2000
Traffic correction factor	T	0.6
Traffic vastage factor	E	1.05
Existing pavement condition	n/a	Smooth, non porous
Surface correction factor	S	0.00 l/m2
Residual asphalt content	R	65%
Aggregate application rate	**C**	**15.9 kg/m2**
Binder application rate, wheelpath	**B_W**	**1.01 l/m2**
Binder application rate, non-wheelpath	**B**	**1.38 l/m2**

McLeod design method calculation for US 2.

Following is a sample of a design calculation using the McLeod method.

Median Particle Size, M (mm): ***9.15 mm***

The Median Particle Size is the theoretical sieve size which 50% of the aggregate passes. Figure 12 below shows how Median Particle Size of WSDOT's gradation 1/2"-US No.4 is determined.



Median particle size

Flakiness Index, FI (% decimal): ***20%***

Flakiness Index is a measure of the shape of the aggregate. With a small sample, it measures how much percentage of the aggregate is flat and elongated.

The flakiness index was estimated 20% based on a visual inspection of the aggregate. A test needs to be done to determine an accurate flakiness index.

Average Least Dimension (ALD), H (mm): **6.7 mm**

The Average Least Dimension is determined by the Median Particle Size and the Flakiness Index. It is calculated as follows:

$$H = \frac{M}{1.139285 + 0.011506 * FI} = \frac{9.15mm}{1.139285 + 0.011506 * 20} = 6.7mm$$

Where;

M = Median Particle Size (mm)

FI = Flakiness Index (%)

Loose unit weight of aggregate, W (kg/m3): **1,600 kg/m³**

Loose unit weight of the aggregate is used for determining how much air void there is between particles in a loose, uncompacted condition. The loose unit weight was estimated 1,600 kg/m3.

Bulk Specific Gravity of aggregate, G: **2.71**

Bulk Specific Gravity is the ratio of the weight of a unit volume of aggregate to the weight of an equal volume of water (INDOT, 2005). The bulk specific gravity for basalt is around 2.71.

Voids in the loose aggregate, V (% decimal): **0.41**

Voids in the loose aggregate approximates the voids between the aggregates once they have been applied by the chip spreader and before they are rolled.

$$V = 1 - \frac{W}{1{,}000 * G} = 1 - \frac{1{,}600\ kg/m3}{1{,}000 kg/m3 * 2.71} = 0.41$$

Where;

W = Loose unit weight of aggregate (kg/m^3)

G = Bulk specific gravity of aggregate

Aggregate absorption, A (% decimal): **<2%**

Aggregate absorption indicates how porous the material is. Aggregate absorption is rarely an issue in the aggregates used in Iceland and Washington State because it rarely exceeds 2%.

Aggregate Absorption Factor, AF: **$0.0\ l/m^2$**

The Aggregate Absorption Factor is a correction of the binder application rate based on aggregate absorption. McLeod suggested a $0.09 l/m^2$ increase in binder application rate for aggregate absorption around 2%. No such increase is necessary in this case.

Traffic correction factor, T: **0.6**

Based on the table below and an average daily more than 2,000 vehicles per day, the traffic correction factor is determined 0.6.

Traffic correction factor

Traffic, ADT	Traffic correction factor, T
<100	0.85
100-500	0.75
500-1000	0.7
1000-2000	0.65
>2000	0.6

Traffic wastage factor, E: **1.05**

McLeod method features a traffic wastage factor that accounts for the aggregate particles that are whipped off the roadway by traffic. The traffic wastage factor was set at 1.05.

Surface correction factor, S: **0.0 l/m²**

Condition of existing surface is an important factor in determining the binder application rate. In this project the existing surface looked good with a tight non-porous surface and therefore the surface correction factor is 0.0 l/m^2.

Table 23 - Surface correction factor

Existing pavement texture	Correction, l/m^2
Black, flushed asphalt	-0.04 to -0.27
Smooth, non porous	0.00
Slightly porous and oxidized	+0.14
Slightly pocked, porous and oxidized	+0.27
Badly pocked, porous and oxidized	+0.40

Residual asphalt content of binder, R (% decimal): **0.65**

Residual asphalt content is the amount of binder remaining on the roadway after evaporation of the cutter or water (Janisch & Gaillard, 1998). The residual asphalt rate for a CRS-2P is on average around 65%.

Aggregate application rate, C (kg/m2): **15.9 kg/m²**

Based on the aforementioned factors, aggregate application rate can now be calculated as follows:

$$C = (1 - 0.4V) * H * G * E = (1 - 0.4 * 0.41) * 6.7 * 2.71 * 1.05 = 15.9\ kg/m2$$

Where;

V = Voids in the loose aggregate (% decimal)

H = Average Least Dimension (mm)

G = Bulk Specific Gravity of the aggregate

E = Wastage factor for traffic whip off

Binder application rate for wheelpaths, BW (l/m2): **1.01 l/m²**

Binder application rate can now be calculated as follows.

$$B = \frac{0.4 * H * T * V + S + A}{R} = \frac{0.4 * 6.7 * 0.6 * 0.41 + 0.0 + 0.0}{0.65} = 1.01\ l/m2$$

Where;

H = Average least dimension (mm)

T = Traffic correction factor

V = Voids in loose aggregate (% decimal)

S = Surface correction factor

A = Aggregate absorption factor

R = Residual asphalt content of binder (% decimal)

Binder application rate for non-wheelpath areas, B (l/m2): **1.38 l/m^2**

The Minnesota Seal Coat Handbook introduces a modification of the binder application rate for non-wheelpath areas. The application rate is calculated as follows:

$$B = \frac{0.4 * M * T * V + S + A}{R} = \frac{0.4 * 9.15 * 0.6 * 0.41 + 0.0 + 0.0}{0.65} = 1.38\ l/m2$$

Where;

M = Median particle size (mm)

T = Traffic correction factor

V = Voids in loose aggregate (% decimal)

S = Surface correction factor

A = Aggregate absorption factor

R = Residual asphalt content of binder (% decimal)

US 2 – Australian method

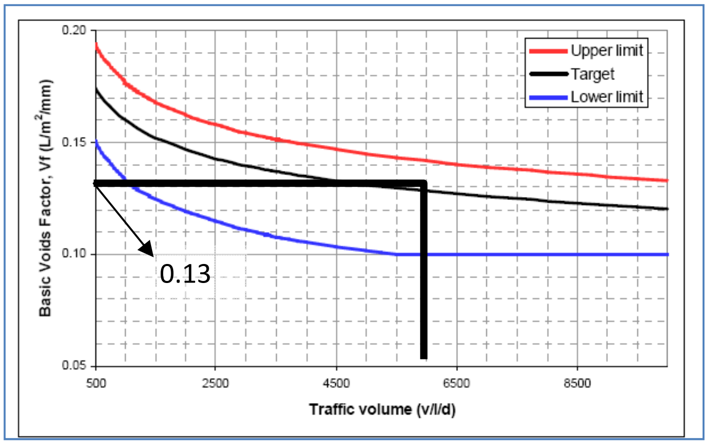
Traffic volume	V/L/D	6,000 V/L/D
Basic void factor	Vf	0.13 l/m2/mm
Aggregate flakiness index	FI	15-25%
Adjustment for aggregate shape	Va	0.00 l/m2/mm
Equivalent heavy vehicles	EHV	0-15%
Adjustment for traffic effects	Vt	0.00 l/m2/mm
Design void factor	VF	0.13 l/m2/mm
Average least dimension of aggregate	ALD	6.66mm
Emulsion factor	Ef	1
Polymer modified factor	Pf	1.1
Basic binder application rate	Bb	0.95 l/m2
Surface texture allowance	As	0.10 l/m2
Embedment allowance	Ae	0.00 l/m2
Binder absorption by pavement	Ap	0.00 l/m2
Binder absorption by aggregate	Aa	0.00 l/m2
Residual content of binder	R	65
Design binder application rate	**Bd**	**1.62 l/m2**
Aggregate application rate		**113 m2/m3**
		14kg/m2
Choke stone application rate		**500 m2/m3**
		3kg/m2

Traffic Volume, V/L/D: **6,000 V/L/D**

Traffic volume is expressed in vehicles per lane per day, V/L/D, based on average daily traffic, ADT. Specific rules apply for multiple lane roadways or for special sections like overtaking lanes and on and off ramps but for a normal two way roadway with one lane in each direction, V/L/D equals ½ ADT. According to WSDOT traffic counts from 2008, the ADT on this road section is around 12,000 vehicles per day or 6,000 vehicles per lane per day.

Basic void factor, Vf (l/m2/mm): **0.13**

The basic void factor is related to traffic and is determined from Figure 14.



Basic void factor for US 2 project. Source (Austroads, 2006)

Aggregate flakiness index, FI (%): **20%**

See McLeod section.

Adjustments to basic void factor:

Adjustments to the basic void factor are made based on aggregate shape and traffic effects.

Adjustment for aggregate shape, Va (l/m2/mm): **0.0 l/m²/mm**

Adjustments on the basic void factor for aggregate shape are based on the type of aggregate, its shape and flakiness index according to Table 8. With a flakiness index of 20%, no adjustment is made.

Basic void factor adjustments for aggregate shape

Aggregate type	Aggregate shape	Flakiness index	Shape adjustment, Va
		%	$L/m^2/mm$
Crushed or partly crushed	Very flaky	>35	Not recommended for sealing
	Flaky	26-35	0 to -0.01
	Angular	15-25	0
	Cubic	<15	+0.01
	Rounded	n/a	0 to +0.1
Not crushed	Rounded	n/a	+0.01

Adjustment for traffic effects, Vt (l/m2/mm): **0.0 l/m²/mm**

Adjustment for traffic effects are based on equivalent heavy vehicle percentage and the roadway alignment according to Table 9. It is assumed that heavy vehicle traffic is around 15% and therefore no adjustment is made.

Basic void factor adjustments for traffic effects

Traffic	Adjustment to Basic Voids Factor, L/m²/mm			
	Flat or downhill		Slow moving - climbing lanes	
	Normal	Channelized*	Normal	Channelized*
On overtaking lanes of multi-lane rural roads where traffic is mainly cars with <10% of HV	+0.01	0.00	n/a	n/a
Non-trafficked areas such as shoulders, medians, parking areas	+0.02	n/a	n/a	n/a
0 - 15% Equivalent Heavy Vehicles	0	-0.01	-0.01	-0.02
16 - 25% Equivalent Heavy Vehicles (EHV)	-0.01	-0.02	-0.02	-0.03
26 - 45% Equivalent Heavy Vehicles (EHV)	-0.02	-0.03	-0.03	-0.04**
>45% Equivalent Heavy Vehicles (EHV)	-0.03	-0.04**	-0.04**	-0.05**

* Channelisation - a systemof controlling traffic by the introduction of an island, or islands, or markings on a carriageway to direct traffic into predetermined paths, usually at an intersection or junction. This also applies to approaches to bridges and narrow colverts

** If adjustments for aggregate shape and traffic effects result in reduction in Basic Void Factor of 0.4 L/m²/mm, consider alternative treatments

Design void factor, VF (l/m2/mm):

Design void factor can now be calculated according to equation 11.

$VF = Vf + Va + Vt = 0.13 + 0 + 0 = 0.13$ l/m²/mm

Where;

Vf = Basic void factor (l/m²/mm)

Va = Adjustment for aggregate shape (l/m²/mm)

Vt = Adjustment for traffic effects (l/m²/mm)

Average least dimension of aggregate, ALD (mm): **6.7 mm**

See McLeod section.

Emulsion factor, Ef: **1.0**

Basic binder application rate is multiplied by the emulsion factor before allowances. If bitumen content of emulsion is higher than 67% the emulsion factor is 1.1, otherwise 1.0. This is to compensate for the reduced reorientation of the aggregate due to increased binder stiffness after initial curing in high bitumen content binders. In this case the bitumen content is 65% and therefore the emulsion factor is 1.0.

Polymer modified factor, Pf: **1.1**

The polymer modified factor is selected according to Table 10. The CRS-2P has a polymer modifier for added adhesion between the binder and the aggregate. Therefore the polymer modified factor is 1.1.

Polymer modified factor. Source (Austroads, 2006)

Class of PMB	PMB factor	Type of treatment
		Aggregate retention (AR)
S10E	1.1	The factors for AR may be increased by 0.1 on low traffic applications, but reduced by 0.1 on high to very high traffic applications and/or high temperature locations in order to minimise flushing.
S35E	1.1	
		Holding treatment (HT)
S10E	1.2	The factors for HT may be increased by 0.1 on low traffic applications, but reduced by 0.1 on high to very high traffic applications and/or high temperature locations in order to minimise flushing.
S35E	1.2	
S45R/S15RF	1.3	
		Weak pavements (WP)
S20E	1.3	The factors for WP may be increased by 0.1 on low traffic applications where maximum waterproofing is desired and the potential for flushing is low, but reduced by 0.1 on very high traffic volume applications.
S45R/S15RF	1.3	
		As a waterproofing seal under OGA (not a SAMI)
S10E, S35E	1.3	Being placed under open graded asphalt, there is little risk of bleeding and the factors should not require further adjustment, although they may be increased, if required, by 0.1 to provide maximum waterproofing.
S45R, S15RF	1.4	
		High Stress Seal (HSS)
S10E, S35E	1.0	Generally these factors should not be adjusted. They may be reduced, if required, by 0.1 on very high traffic applications and/or hot to very hot locations to minimise flushing or binder pick-up.
S20E, S45R, S15RF	1.1	
M500/170	1.1	
		Strain Alleviating Membrane (SAM)
S10E	1.2	The SAM factors are designed to provide the maximum practicable binder application rate to optimise resistance to reflective cracking and to waterproof the pavement. They may be reduced, if required, by 0.1 on very high traffic applications and/or hot to very hot locations to minimise flushing or binder pick-up.
S20E	1.3	
S35E	1.2	
S45R, S15RF	1.4	
		Strain Alleviating Membrane Interlayer (SAMI)
S25E	1.6	The SAMI factors are designed to optimise the resistance to reflective cracking under Dense Graded Asphalt. The factors may be increased by as much as 0.5 when the SAMI is designed to minimise reflective cracking under Open Graded Asphalt.
S55R, S20RF	1.8	

Basic binder application rate, Bb (l/m2):

The basic binder application rate is calculated as follows:

$Bb = Vf * ALD * Ef * Pf = 0.13 * 6.7 * 1.0 * 1.1 = 0.96$ l/m^2

Where;

Vf = design void factor (l/m^2/mm)

ALD = average least dimension of aggregate (mm)

Ef = emulsion factor

Pf = polymer factor

Adjustments to basic binder application rate:

A number of adjustments and allowances are made to the basic binder application rate.

Surface texture allowance, As (l/m2): **0.1 l/m^2**

Binder application rate is adjusted according existing surface's texture. The surface texture allowance is determined by Table 11. The existing surface of the roadway was in good condition, therefore a low surface texture allowance of 0.1 l/m^2 was used.

Surface texture allowance for existing surfacing, As. Source (Austroads, 2006)

Aggregate size of proposed seal	Measured texture depth (mm)	Surface texture allowance (L/m²)
Existing: 14, 16 or 20 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.6	Note 2
	0.7 to 0.9	+0.1
	1.0 to 1.3	+0.2
	1.4 to 1.9	+0.3
	2.0 to 2.9	+0.4
	>2.9	+0.5
10 mm	0 to 0.3	-0.1
	0.4 to 0.5	0
	0.6 to 0.7	+0.1
	0.8 to 0.9	+0.2
	1.0 to 1.3	+0.3
	1.4 to 1.8	+0.4
	>1.8	Note 3
14 mm	0 to 0.3	-0.1
	0.4 to 0.5	0
	0.5 to 0.6	+0.1
	0.6 to 0.7	+0.2
	0.8 to 0.9	+0.3
	1.0 to 1.3	+0.4
	1.4 to 1.8	+0.5
	>1.8	Note 3
Existing: 10 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.9	+0.1
	1.0 to 1.4	+0.2
	1.5 to 2.0	+0.3
	2.1 to 2.7	+0.4
	>2.7	+0.5
10 mm	0 to 0.3	Note 1
	0.4 to 0.7	+0.1
	0.8 to 1.1	+0.2
	1.2 to 1.7	+0.3
	>1.7	Note 3
14 mm	0 to 0.2	Note 1
	0.3 to 0.6	+0.1
	0.7 to 0.9	+0.2
	1.0 to 1.2	+0.3
	1.3 to 1.7	+0.4
	>1.7	Note 3

Aggregate size of proposed seal	Measured texture depth (mm)	Surface texture allowance (L/m²)
Existing: 5 or 7 mm seal		
5 or 7 mm	0 to 0.3	Note 1
	0.4 to 0.9	+0.1
	1.0 to 1.5	+0.2
	1.6 to 2.2	+0.3
	2.3 to 3.2	+0.4
	>3.2	+0.5
10 mm	0 to 0.3	Note 1
	0.4 to 0.7	+0.1
	0.8 to 1.1	+0.2
	1.2 to 1.8	+0.3
	>1.8	Note 3
14 mm	0 to 0.2	Note 1
	0.3 to 0.6	+0.1
	0.7 to 0.9	+0.2
	1.0 to 1.4	+0.3
	1.5 to 2.0	+0.4
	>2.0	+0.5
Existing: asphalt/slurry surfacing		
All	0 to 0.1	0
	0.2 to 0.4	+0.1
	0.5 to 0.8	+0.2
	0.9 to 1.4	+0.3
	>1.4	+0.4

Notes:

1. Embedment considerations dominant
2. Specialised treatments necessary
3. This treatment might not be advisable depending on the shape and interlock of aggregates so alternative treatments (surface enrichment, small size seal or others) should be considered
4. For application of aggregate sizes greater than 14 mm, adopt allowances applicable to 14 mm aggregate.

Embedment allowance, Ae (l/m2): **0.0 l/m²**

If the existing surface is soft enough for the chip sealing aggregate to penetrate it, embedment allowance will decrease the binder rate. The embedment allowance is mostly used in initial sealing jobs, not in reseals. No embedment allowance was used for this design.

Binder absorption by pavement adjustment, Ap (l/m2): **0.0 l/m²**

Binder absorption by pavement is mainly aimed at initial treatments. If an existing chip seal or HMA pavement is visibly open and porous, other measures have to be considered prior to chip sealing like primesealing. No binder absorption by pavement was used for this design.

Binder absorption by aggregate, Aa (l/m2): **0.0 l/m²**

Binder absorption by aggregate is normally not a problem and does usually not exceed 0.1l/m^2 (Austroads, 2006). No binder absorption by aggregate was used for this design.

Residual content of binder, R (% decimal): **0.65**

See McLeod section.

Design binder application rate, Bd (l/m2): **1.63 l/m²**

Design binder application rate is calculated as follows:

$$Bd = \frac{Bb+As+Ae+Ap+Aa}{R} = \frac{0.96+0.1+0.0+0.0+0.0}{0.65} = 1.63 \text{ l/m}^2$$

Where;

Bb = basic binder application rate (l/m^2)

As = surface texture allowance (l/m^2)

Ae = embedment allowance (l/m^2)

Ap = binder absorption by pavement (l/m^2)

Aa = binder absorption by aggregate (l/m^2)

R = residual content of binder (% decimal)

Aggregate application rate (m2/m3) **14.3 kg/m²**

Table 11 displays the aggregate application rate for a single layer of aggregate of 10mm or bigger. It also gives an application rate of the same layer with a scatter coat or choke seal layer applied on top of it.

In this design, the first layer is calculated as:

$$\frac{750}{ALD} = \frac{750}{6.7} = 112 \text{ m}^2/\text{m}^3$$

Assuming a loose unit weight of the aggregate of 1,600kg/m^3, the application rate will be:

$$\frac{1{,}600 \, {}^{kg}/_{m^3}}{112 \, {}^{m^2}/_{m^3}} = 14.3 \, kg/m^2$$

Choke seal application rate:

$$\frac{1{,}600 \, {}^{kg}/_{m^3}}{500 \, {}^{m^2}/_{m^3}} = 3.2 \, kg/m^2$$

Aggregate spread rate for sizes >10mm with emulsions

Application		Aggregate spread rate, (m^2/m^3)	
		Traffic < 200 v/l/d	Traffic > 200 v/l/d
Single layer of aggregate		750 / ALD	700 / ALD
Layer of large aggregate plus scatter coat of 7mm or smaller	First layer	800 / ALD	750 / ALD
	Scatter layer	400 - 600	400 - 600

R 829 - Eyjafjordur – McLeod method

Median particle size	M	12.75mm
Flakiness index	FI	15.0%
Average least dimension	H	9.72mm
Loose unit weight	W	1,600 kg/m3
Bulk specific gravity	G	2.8
Voids in loose aggregate	V	0.428
Aggregate absorption	A	<2%
Aggregate absorption factor	A_F	0.00 l/m2
Traffic volume	ADT	500-1000
Traffic correction factor	T	0.7
Traffic vastage factor	E	1.05
Existing pavement condition	n/a	Slightly porous and oxidized
Surface correction factor	S	0.14 l/m2
Residual asphalt content	R	100%
Aggregate application rate	**C**	**23.7 kg/m2**
Binder application rate, wheelpath	**B_W**	**1.30 l/m2**
Binder application rate, non-wheelpath	**B**	**1.66 l/m2**

R 829 - Eyjafjordur – Australian method

Traffic volume	V/L/D	500 V/L/D
Basic void factor	Vf	0.18 l/m2/mm
Aggregate flakiness index	FI	15-25%
Adjustment for aggregate shape	Va	0.00 l/m2/mm
Equivalent heavy vehicles	EHV	0-15%
Adjustment for traffic effects	Vt	0.00 l/m2/mm
Design void factor	VF	0.18 l/m2/mm
Average least dimension of aggregate	ALD	9.72mm
Polymer modified factor	Ef	1.1
Emulsion factor	Pf	1
Basic binder application rate	Bb	1.87 l/m2
Surface texture allowance	As	0.20 l/m2
Embedment allowance	Ae	0.00 l/m2
Binder absorption by pavement	Ap	0.00 l/m2
Binder absorption by aggregate	Aa	0.00 l/m2
Residual content of binder	R	100%
Design binder application rate	**Bd**	**2.07 l/m2**
Aggregate application rate		**82 m2/m3**
		20kg/m2
Choke stone application rate		**400 m2/m3**
		4kg/m2

SR 262 – McLeod method

Median particle size	M	6.27mm
Flakiness index	FI	15.0%
Average least dimension	H	4.78mm
Loose unit weight	W	1,600 kg/m3
Bulk specific gravity	G	2.71
Voids in loose aggregate	V	0.409
Aggregate absorption	A	<2%
Aggregate absorption factor	A_F	0.00 l/m2
Traffic volume	ADT	100-500
Traffic correction factor	T	0.75
Traffic vastage factor	E	1.05
Existing pavement condition	n/a	Smooth, non porous
Surface correction factor	S	0.00 l/m2
Residual asphalt content	R	65%
Aggregate application rate	**C**	**11.4 kg/m2**
Binder application rate, wheelpath	**B_W**	**0.90 l/m2**
Binder application rate, non-wheelpath	**B**	**1.18 l/m2**

SR 262 – Australian method

Traffic volume	V/L/D	300 V/L/D
Basic void factor	Vf	0.19 l/m2/mm
Aggregate flakiness index	FI	15-25%
Adjustment for aggregate shape	Va	0.00 l/m2/mm
Equivalent heavy vehicles	EHV	0-15%
Adjustment for traffic effects	Vt	0.00 l/m2/mm
Design void factor	VF	0.19 l/m2/mm
Average least dimension of aggregate	ALD	4.39mm
Polymer modified factor	Ef	1.1
Emulsion factor	Pf	1
Basic binder application rate	Bb	0.89 l/m2
Surface texture allowance	As	0.10 l/m2
Embedment allowance	Ae	0.00 l/m2
Binder absorption by pavement	Ap	0.00 l/m2
Binder absorption by aggregate	Aa	0.00 l/m2
Residual content of binder	R	65%
Design binder application rate	**Bd**	**1.53 l/m2**
Aggregate application rate		**180 m2/m3**
		9kg/m2
Choke stone application rate		**N/A**
		N/A

R33 - Gaulverjabaer – McLeod method

Median particle size	M	12.45mm
Flakiness index	FI	15.0%
Average least dimension	H	9.49mm
Loose unit weight	W	1,600 kg/m3
Bulk specific gravity	G	2.7
Voids in loose aggregate	V	0.407
Aggregate absorption	A	<2%
Aggregate absorption factor	A_F	0.00 l/m2
Traffic volume	ADT	100-500
Traffic correction factor	T	0.75
Traffic vastage factor	E	1.05
Existing pavement condition	n/a	Badly pocked, porous and oxidized
Surface correction factor	S	0.41 l/m2
Residual asphalt content	R	100%
Aggregate application rate	**C**	**22.5 kg/m2**
Binder application rate, wheelpath	**B_W**	**1.57 l/m2**
Binder application rate, non-wheelpath	**B**	**1.93 l/m2**

R 33 - Gaulverjabaer – Australian method

Traffic volume	V/L/D	150 V/L/D
Basic void factor	Vf	0.20 l/m2/mm
Aggregate flakiness index	FI	15-25%
Adjustment for aggregate shape	Va	0.01 l/m2/mm
Equivalent heavy vehicles	EHV	0-15%
Adjustment for traffic effects	Vt	0.00 l/m2/mm
Design void factor	VF	0.21 l/m2/mm
Average least dimension of aggregate	ALD	9.10mm
Polymer modified factor	Ef	1.1
Emulsion factor	Pf	1
Basic binder application rate	Bb	2.10 l/m2
Surface texture allowance	As	0.40 l/m2
Embedment allowance	Ae	0.00 l/m2
Binder absorption by pavement	Ap	0.00 l/m2
Binder absorption by aggregate	Aa	0.00 l/m2
Residual content of binder	R	100%
Design binder application rate	**Bd**	**2.50 l/m2**
Aggregate application rate		**82 m2/m3**
		20kg/m2
Choke stone application rate		**N/A**
		N/A