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Determination of Optimum Nominal Aggregate Size for Single Surface Dressings

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Abstract : Surface dressings can be used as a successful road maintenance activity if carried out properly. One of the main decisions to be taken in designing a surface dressing in road maintenance is the selection of appropriate aggregate size. Improper selection could tarnish the performance of a surface dressing. The aim of this study is to find the optimum size of aggregate for a single surface dressing, especially in Sri Lankan Macadam roads. General size of aggregate for a particular surface dressing could be found using two parameters, commercial traffic volume on road and surface hardness of the road based on many available highway literature. But the aggregate sizes selected in above simple method have shown inconsistent results in Sri Lankan roads. Therefore tests were carried out to find the most appropriate aggregate size for the surface dressings in medium to low traffic Macadam roads in maintenance operations.

Three most suitable nominal sizes of aggregates were selected using commercial traffic volume and the road surface hardness to begin the tests. These three sizes of aggregates were used to carry out three different surface dressings in the same road but in different stretches. Binder type were kept constant and binder rate was changed according to the aggregate size. The performances of these three surface dressings were evaluated by measuring aggregate removal rate and skid resistance. Digital photographs of demarcated locations in surface dressings of different aggregate sizes were taken at pre determined time intervals. The numbers of aggregate were counted in each photo after certain time intervals up to 12 weeks and using this data, the behavior of each surface dressing over a period of time was studied. The aggregate size that could keep most of aggregate intact in its dressing after a certain time period would be a more durable chip size.

The next aspect of checking performance of the dressing is the skid resistance. The techniques utilized to measure this value are Locked wheel test and Sand patch method. These tests were done after 12 weeks since the operation a sufficient enough to stabilize the dressing. The comparison of aggregate retention on road surface and the skid resistance after 12 weeks will give the short term performance of three aggregate sizes. It was found that 9.5mm aggregate size has better performance in aggregate retention and the 12.5mm size has better skid resistance.

Keywords : SBST, Surface dressings, Chipping, , Maintenance, Skid resistance, Low volume roads

1.Background of surface dressings

Surface dressing is a simple, highly effective and inexpensive road surface treatment. This method is used throughout the world for surfacing mainly the medium to light trafficked new roads. Also it can be used as a maintenance treatment in all kinds of roads and is capable of greatly extending the life of a structurally sound road pavement, if the treatment is undertaken at the correct time. Its ability to prevent ingress of water to underlying layers of the road pavement could retard the failure of structurally weak pavement. Surface dressing comprises a thin film of binder, generally bitumen, which is sprayed on to the road surface and a layer of stone chippings which covers the binder layer. The thin film of binder acts as a water proofing seal preventing the entry of surface water in to the road structure. The stone chippings protect this film of binder from damage by vehicle tyres, and form a durable skid resistant and dust free wearing surface. In some circumstances the

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process may be repeated to provide double or triple layers of aggregates.

The most important aspect of the surface dressing is the adhesion of aggregates to the road surface. Therefore both the chippings and the road surface must be clean and free from dust during the surface dressing process. Inappropriate specifications, poor materials, and bad workmanship, can also drastically reduce the service life of a surface dressing. There are several types of surface dressings and methods of carrying out surface dressings. The appropriate selection has to be made based on site conditions, availability of funds, technology adopted and materials. Single surface dressing is the most common application for existing bituminous roads. It can be basically used to waterproof the road surface fulfilling the function of a maintenance reseal.

Hot mix asphalt overlays are costly and needs lots of pre overlay repairs on road surface. When comparing with surface dressing, overlays are durable and have a less chance of making mistakes in the operation. Overlays are good for heavy traffic volume roads. Therefore it is necessary to select the most suitable surfacing based on traffic volume, existing road condition and availability of funds. Slurry sealing is also used as a surfacing but not as widely as chip seals, because it is costly and time consuming compared with chip seals. One of the important advantages of finished surface dressing's surface over other methods is its higher skid resistance. The exposed aggregate surface will give good surface texture and skid resistance. However it must be emphasized that a surface dressing cannot restore the riding quality of an already misshapen road and the surface being treated must be sound, clean and have a uniform texture to obtain good results.[8] A surface dressing which is simply a thin layer of aggregate held by a film of binder has no structural strength of its own.

Surface dressing applications in Sri Lanka

Asphalt roads comprise only 15% of all the Roads managed by the Road Development Authority (RDA) though this has been increasing steadily. Penetration macadam roads consist 67% of all RDA roads. 5% of roads are surface treated and the rest are concrete or gravel roads. This means more than 75% of RDA roads are candidates for surface dressings. This situation leads to finding a suitable periodic surface maintenance technique to be adopted for roads other than asphalt roads. The options available are basically limited to surface treatments such as sand sealing, surface dressings and slurry seals. Sand sealing has been used extensively but it lasts one to one anda half years only. Meantime slurry sealing is proved to be costly and time consuming compared to chip sealing. Therefore single surface dressings which can last 3-5 years are a more appropriate surface treatment. There was a lot of research conducted on different aspects of the process in Sri Lanka [6, 2]. Hence it has been considerably developed over the years.

Usage of pneumatic rollers, spreaders and improved sprayers has contributed greatly to this development. Surface dressing is being utilized as a road maintenance technique as well as surfacing of new roads in Sri Lanka. The types of surface dressing used in Sri Lanka are single dressing and double dressing which are called here as Single Bituminous Surface Treatment (SBST) and Double Bituminous Surface Treatment (DBST). The specification for above work has been provided in Standard Specification for Construction and Maintenance of roads and bridges (SSCM) by Road Development Authority [10].

The surface dressings are a good option for our roads because of several prevailing conditions in our country.

01. Financial restraints for more costly techniques such as hot mix overlays.
02. Availability of abundant manpower.
03. Favoured weather conditions prevailing in the country.
04. 75% of RDA roads are either penetration Macadam roads or surface dressed roads.

2. Problem Statement

Selection of proper seal requires experience and sound technical knowledge of surface dressings work. The major factors such as road surface hardness, commercial traffic volume have to be determined prior to the surface dressing design. Soft road surfaces require larger aggregates and hard surfaces should be dressed with smaller chips. Heavy commercial vehicles tend to embed the aggregate in to the road surface and to avoid this it is necessary to use larger chips when heavy vehicle traffic volume is high. The aggregates used for the dressing basically should be single size and in cubical shape. These properties can be checked by testing the materials at a laboratory. However, the selection of aggregate size for a particular dressing is an issue faced by the engineer

Comparisons with RDA specifications and TRRL Road Note-3 rates

The spray rate of emulsion CRS2 can be calculated considering site conditions and other parameters relevant to surface dressing. CRS2 spray rate calculations were done based on Road Note3 guidelines.[8,9,10] The spray rate of emulsion calculated above was within the RDA's SSCM stipulated range as shown in Table 1. Therefore applying Road Note 3 rates does not violate SSCM specifications.

However TRRL method does not give calculations leading to exact spread rate of aggregates. Instead it recommends carrying out a general site trial. The spread rate of each type of chip is evaluated using site test and again found to be within the SSCM specifications. Then the only other main variable is the aggregate grading limits. Here Road Note 3 recommends specification given in BS63: Part 2:1987. However RDA has its own specification given in the SSCM. [5,8,10]

Table 1 Comparison of CRS2 spray rates

Aggregate Size (mm)	CRS2 Spray rate, Road Note 3 Lit./m2	CRS2 Spray rate, SSCM of RDA lit./m^2
6.3	1.06	0.75 -1.14
9.5	1.17	0.98 - 1.36
12.5	1.28	1.14 - 1.51

3. Field testing procedure

Testing was done in 30m long road sections for each aggregate size. Therefore total length for three sizes would be 90m. The dimensions of each test spot are 200 X 200 mm square located on possible wheel paths. Each test section will have 12 test spots located along vehicle wheel paths. The locations of these 12 test spots within a test section are selected randomly.

The first 30 m section was done with 6.3 mm aggregates and consecutive 30m sections were surface dressed with 9.5 mm and 12.5 mm aggregates. Pneumatic roller was used to obtain a stable orientation for the mosaic of chips. That is to settle the chips in a more stable manner so that vehicle loading can be sustained without dislodging from the dressing. It is important however to complete the rolling operation before the breaking (hardening) of emulsion. Traffic was not allowed to travel on newly dressed surface for up to 2 hrs. Even after 2 hrs, the traffic was allowed to travel in a controlled manner with a speed of 20 - 30 km/hr.

Aggregate removal test

The durability of the dressing is measured as the ability of the chips to adhere to the dressing after emulsion was cured. The loss of chips could be measured with time. This was done by marking 200 mm x 200 mm test spots on the dressed surface. The digital photographs of the dressing test spots were taken just after the dressing when compaction is completed. Each spot was given an identification number and it should be tagged before taking photos.

The pictures should be taken from vertically above the test spot and. should be in high resolution so that the number of aggregates can be counted within the test spot. Sample photographs of two locations are shown in Figure 1. These pictures were taken at the same spot 1 week, 3 weeks, 7 weeks and 12 weeks after the dressing, so that loss of aggregate can be counted in each 36 test spots of the dressing during the preceding weeks. The number of aggregates in each photo were counted and recorded. It is important that some counting convention is maintained from the beginning. The counting will show different results if two persons counted the same spot. Therefore a single person should count the number of aggregates in a spot. It will give more consistent counts.

Summary of statistical data of aggregate count is given in Table 2.

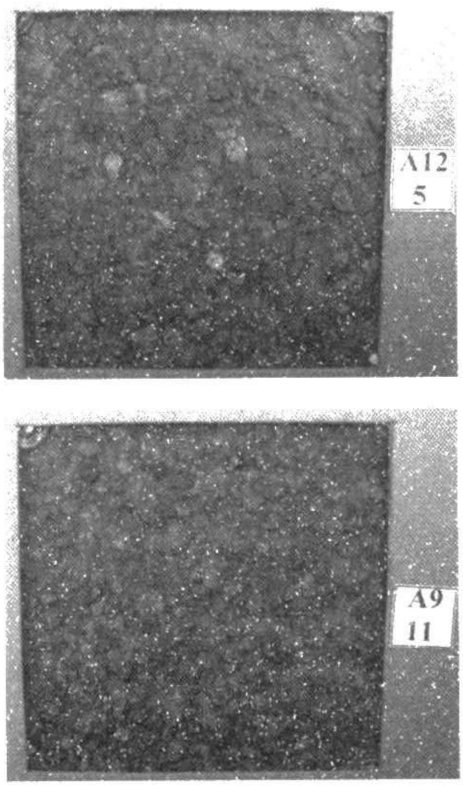

Figure 1. Sample pictures of A9-11 and A12-5 test

Skid Resistance

1. Locked wheel test

The second objective was to carry out a lock wheel test and a sand patch test to determine and compare the skid resistance of each size of aggregate surfaces. The first test was done using a motor vehicle. It was carried out after twelve weeks from the date of surface dressing. Curing of the emulsion should be completed by this time and aggregates should be fully settled on the road surface. The test vehicle was driven at a constant speed of 40 km/hr and the driver was instructed to apply brake suddenly in full force at the previously demarcated location on test area. A flagman standing at marked location of the road was used to signal the braking location. Once the wheels are in locked position the vehicle will skid along the road until it stops at a certain distance. The distance from the location where brakes were applied suddenly to the stop location was measured and recorded. Similarly 5 tests were carried out for each of the 3 sizes of aggregates.

2. Sand Patch Test

A known quantity of sand is spread on a randomly selected place of the road surface. The sand is spread evenly down to the top level of chips. The sample should appear in circular shape after the spreading. The diameter of the circle was measured. This way the same type of sand was utilized to do the test in other places as well. The diameters of all circles were measured. These data can be used to calculate sand patch thickness which is an indication of a macro texture of the road surface.

Table2 Statistical data of aggregate count

Test section		At start	After 1 wk.	After 3 wk.	After 7 wk.	After 12 wk.	%loss
6.3 mm	Ave	6311	3711	2955	2622	2199	655
	Std.	46	51	48	50	41	6
	Max	703	442	387	340	261	79
	Min	542	271	231	174	114	59
9.5 mm	Ave	392	332	291	262	247	37
	Std.	14	20	19	26	25	8
	Max	416	359	318	310	300	48
	Min	370	291	265	224	214	19
12.5 mm	Ave	312	224	195	178	171	45
	Std.	28	29	22	28	29	10
	Max	358	286	239	232	224	56
	Min	259	187	166	142	133	26

Analysis of aggregate counting data

The data of aggregate counts shows that aggregates are removed from the surface dressing regularly over the time. It is necessary to find out the pattern of removal of aggregates with time. Figure2 shows the loss of aggregates at different time intervals. It shows that removal of aggregates has generally reduced as time progresses.

The rate of loss of aggregates from road surface varies with time. This phenomenon is important in predicting future trends as well as analyzing the past behavior of the surface dressing. Reduction in rate of removal shows that stabilization of dressing occurs after a certain time interval.

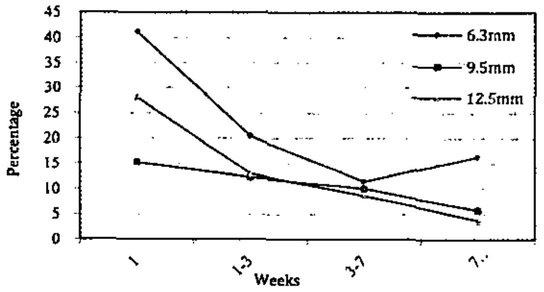

Figure 2 Average aggregate losses in each period

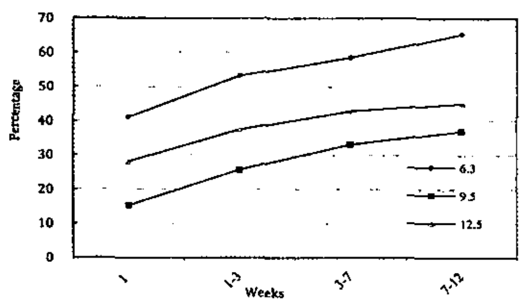

Figure 3 Cumulative Percent of aggregates loss after initial count

Most of the aggregates lost from the dressing was during first seven days and then it stabilizes and continues to reduce the aggregate loss from the surface dressing. The higher disintegration of aggregates initially is due to lack of adherence between the chip and the existing surface. Aggregates that are directly in contact with the binder will hold firm to the road surface whereas the aggregates that fall between other chips will not have enough binder to adhere to surface. Those aggregates will lose contact at the beginning. The other reason is emulsion takes 2-3 days to fully stabilize after evaporating the volatile substance. The aggregates are vulnerable to moving traffic specially the heavy vehicles when emulsions are not fully settled. The chances of retaining chips can be increased by either controlling or prohibiting the traffic from dressed area at least first 3-4 days.

The smallest aggregate size used for the test was 6.3 mm nominal size and it has the poorest record from the durability check. It had lost 65 percent of aggregates from the surface after 12 weeks. However all these 6.3mm aggregates were not disintegrated from the surface but large number of them have penetrated in to the road. This is clearly visible when comparing the photographs and during the field inspections. This situation is undesirable because intended purpose will not be served from the surface dressing as binder could be exposed to vehicle tyres and wear off quickly. Most of the Sri Lankan roads show somewhat similar pavement characteristics as well as traffic compositions and this means 6.3mm aggregates will behave similarly in other roads as well.

The next aggregate which is 9.5 mm nominal size shows contrasting results. It had lost only 37% of aggregate compared to 65% lost in 6.3mm size within first 12 weeks. The important aspect in 9.5mm chip was it had resisted the penetration in to the road pavement against traffic loading. Further, it was able to adhere to surface without disintegration from the surface. This aggregate size is ideal for a surface dressing as it shows durability compared to other types at all stages of the evaluation.

The third type is 12.5 mm aggregates and it had lost 45 % of the original aggregates after 12weeks. The main problem with 12.5 mm aggregates was it tends to get whipped off from the road due to traffic. However it quickly gathers the bonding strength and lose fewer aggregates after 7 weeks as shown in Figures 2 and 3. During the period 7-12 weeks it had lost only 3.82 percent which is good compared to other aggregates. But the problem was, even though it lost relatively less percentage of aggregates the exposed road surface is higher as aggregates dimension is large compared to the other two.

Statistical test for aggregate removal

When the aggregates are removed from the road surface, binder will be exposed to the vehicle tyres. This is a critical factor for the durability of the surface dressing. The chip removal data can be used to evaluate the exposed areas of each test spot. These exposed areas of different aggregate sizes can be used to compare the performance of different aggregate sizes. Hypothesis testing was done to check the statistical difference of means of different aggregate sizes after 12 weeks.

Hypothesis Testing

Null hypothesis (H_0);

(Mean percent of aggregate removal)$_{i,i}$ = (Mean percent of aggregate removal)$_{i,j}$

Where; $i \neq j$

i,j = 6.3mm, 9.5mm, 12.5mm

Alternate hypothesis (H_1);

(Mean percent of aggregate removal)$_{i,i}$ = (Mean percent of aggregate removal)$_{i,j}$

at significance level of 5% . This is a two tail test.

Table 3 Hypothesis test results

Aggregate size Comparison		t-statistic	Critical t-value	Reject null hypothesis (Y/N)
6.3mm	9.5mm	9.77	1.76	Y
6.3mm	12.5mm	5.47	1.75	Y
9.5mm	12.5mm	-1.98	1.72	Y

Table 3 results show that the null hypothesis has to be rejected as t statistics lie outside the critical range. Therefore means of surface exposed areas in different aggregate sizes are not equal and different at 0.05 confidence level, so that aggregate removal is different in three sizes of aggregates.

4. Skid resistance data

1. Locked wheel test data and analysis

Table 4 shows the locked wheel test results of the 3 sections. Stopping distance was measured in five trials at each section

Table 4 Skidding distances by locked wheel method

Size (mm)	Stopping Distance, (m)					
	Tria l 1	Trial 2	Trial 3	Trial 4	Trial 5	Av.
6.3	9.10	8.70	8.30	9.60	9.30	9.00
9.5	6.90	6.35	8.10	7.80	7.10	7.25
12.5	6.60	5.65	4.90	5.15	5.70	5.60

Using the equation below [1, 4, 7]

$$SN = 100[(W/g)(40^2/2d) + P]/W$$

Where W = Vertical reaction force due to vehicle weight, P= Pulling force, d= distance to stop the vehicle from braking point, SN = Skid number

P can be considered as zero because when the vehicle starts braking there won't be any forward thrust applied by the vehicle.

Therefore

$$\mathbf{SN = 629.24/d} \quad \text{———————(a)}$$

Considering the skid distance data from the Table 4 and above equation (a), following skid numbers can be computed as shown in Table 5.

Table 5 Computed Skid numbers

Agg. Size (mm)	Skid numbers					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Av.
6.3	69	72	75	65	67	70
9.5	91	99	77	80	88	87
12.5	95	111	128	122	110	113

Some of the skid numbers are higher than value 100. This is due to usage of four vehicle tyres for braking. The frictional resistance generated by four tires could decrease the skidding distance and in effect increase the skid number. However these results are adequate for comparison purposes.

The results show that as aggregate size increases the skid number also increased as expected. The results clearly indicate the different aggregate size surfaces have different numbers and not even a single data overlap skid numbers of other surfaces. Surface of chip size 12.5 mm has shown better results having average skid numbers of 113.50 and in second is 9.5 mm having 87.42. When comparing these results it is obvious that 12.5 mm has good skid resistance properties.

2. Sand Patch Test Data and Analysis

Tables 6 and 7 shows the sand patch diameters and sand patch thickness at trial locations respectively for the three sections

Table 6 Sand Patch Diameters

	Sand Patch Diameter (mm)					
Size (mm)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Av.
6.3	220	260	302	289	274	269
9.5	221	214	217	225	209	217
12.5	196	201	198	210	223	205

Table 7 Sand patch thickness

Agg. size	Sand Patch thickness (mm)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
6.3	2.10	1.51	1.12	1.22	1.36	1.46
9.5	2.08	2.22	2.16	2.01	2.33	2.16
12.5	2.65	2.52	2.60	2.31	2.05	2.42

Sand patch thickness is also an indication of surface texture depth and is known to have an influence on the skidding resistance afforded to moderate and high speed traffic. Recent research by different highway agencies suggests that the influence of low texture depth becomes apparent at lower speed than was previously thought [1]. Texture depth measurement has to be considered even if locked wheel tester gives results of skid resistance at certain speed (40km/hr). Therefore both locked wheel test and surface texture depth results should be considered simultaneously to evaluate the skid resistance in different speed categories.

COMPARISON OF OVERALL RESULTS

The results from both tests shall be compared in order to arrive at a conclusion.

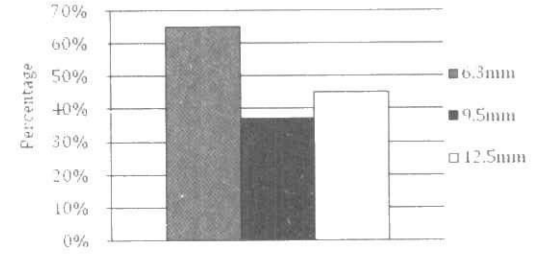

Figure 4 Percent aggregate removal after 12 weeks

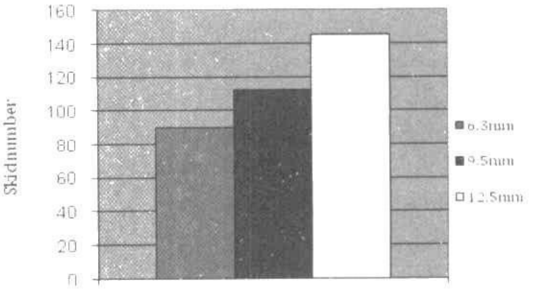

Figure 5 Skid numbers of three chip sizes

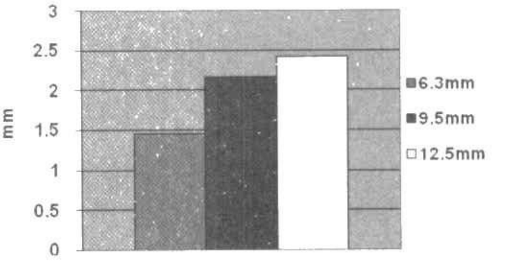

Figure 6 Sand patch thicknesses

These results show that 12.5 mm aggregate has the skid resistance in both tests and 9.5 mm section has the second best values in both tests.

The comparison of three sizes of chips shows that 9.5 mm aggregate has performed better than the other two types in durability aspect.

Application of test results to other roads

A certain aggregate size qualified for a particular road or road section may not be appropriate for other places. Therefore a brief study was done to ascertain whether these parameters fall in to certain traffic and hardness category in B class of roads maintained by RDA. The above research was carried out for a B class road and it is appropriate to check whether the surface hardness and heavy vehicle ADT in other B class roads. The two main characteristics of a road that should be considered when designing a surface dressing are

1 Surface hardness.
2 ADT of heavy vehicles for the road.

The size of surface dressing aggregate is influenced by the above two factors. Routine maintenance techniques such as surface treatments employed by RDA are similar in nature and therefore surface hardness tends to be similar in most of the macadam roads. Surface treatments such as sand sealing and aggregate seals are common in road and leads to similar surface characteristics. The surface dressing requires only the surface hardness but not the hardness inside the base. Therefore it can be concluded that surface hardness in macadam roads lie in "Hard" range.

Daily heavy vehicle volumes in most of the B class roads tend to lie within 200-1000 vehicles. Therefore, traffic category is also similar in most of the B class roads. The ADT data collected for some of the B class roads by Data Collection Unit of RDA shows that 85% of roads fall in to the same category.

Conclusions

The results of aggregates removal test shows that 9.5 mm aggregates performed better than the other two types (Figure 4). The losing of aggregates from road surface can occur either due to disintegration or due to penetration in to the pavement. This will expose original road surface and if it exceeds a certain level then binder layer could be damaged due to vehicle tyres. The 9.5 mm aggregates have lowest aggregate removal rate of 37% and compared with other two types it is a good value.

On the other hand 6.3 mm chips show poor results mostly due to penetration of aggregates in to the pavement and also due to bleeding. Therefore 6.3 mm chips cannot be recommended for surface dressings under these conditions. The 12.5 mm chip size has lost 45 % of aggregates due to whipping off of chips by traffic. Loosing of this much of chips could damage the binder when exposed to the vehicle tyres. This aggregate size has shown good skid resistance properties but its survival in long term is the factor which determines its suitability. However it is apparent that 12.5 mm has lost fewer aggregates as time progresses.

Following conclusions can be made as a summary based on information discussed previously.

1. 9.5 mm aggregates show comparatively better results in terms of chip retaining. It lost fewer aggregates compared to 12.5mm and 6.3mm nominal sizes.
2. 12.5mm aggregate has the highest skid numbers from locked wheel tests and surface texture depth from sand patch test.
3. Considering above information, 9.5mm performed better in aggregate removal test whereas 12.5mm has shown better skid resistance. Therefore it can be concluded that if the aggregate retention is a priority then 9.5mm chips are suitable and on the other hand if skidding is a major concern then 12.5mm aggregates is appropriate for the surface dressing.

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