Degradation of Dense Aggregate Gradings

BALA SUBRAMANYAM AND MOWLI P. PRATAPA

As the degradation of aggregates affects the properties of bituminous concrete, various aspects connected with degradation are studied in this article. These include the effect of the method of representation of degradation, the necessity of using an appropriate method to represent degradation, and the effect of type and pattern of grading on degradation. It is observed that the amount of degradation and the order of the gradings change depending on the method adopted to represent it. The defect in using the more popular method (i.e., the suface area method) to represent the degradation of dense gradings is explored, and the authors show that representing degradation by percent increase in the fine aggregate of a grading is more appropriate. The selected dense gradings (i.e., Fullers, practical continuous, skip and semigap gradings) used in different countries in three maximum sizes (25 mm, 20 mm, and 12.5 mm) are degraded in the Los Angeles abrasion machine by a modified procedure to study the effect of maximum size, type, and pattern of the gradings on degradation. It is observed that semigap-type gradings degrade less, and the pattern of gradings is important in the degradation of aggregate gradings.

Of the several types of bituminous pavements, bituminous concrete pavements are considered to be the best type. Several types of dense gradings are used in the construction of these pavements in various countries. In the United States, India, etc., mostly continuous gradings are used. In the United Kingdom and South Africa, semigap gradings are adopted. Skip gradings are also tried in the United States, and their behavior is studied there and in India. Each type has its own advantages and disadvantages. These can be determined by studying their behavior either in the field or under laboratory conditions. Field studies involve high expenditures, many difficulties, long periods of time, and a lesser possibility of studying the effect of several variables. So, to study at least the relative behavior of some of the dense gradings used in different countries, a simple laboratory procedure has been developed and used by Bala Subramanyam (unpublished data) in his research.

In this procedure the selected gradings are degraded in the Los Angeles abrasion machine (L.A.M.) using six balls and rotating the drum in a different number of revolutions. Using these gradings resulting from degradation in the L.A.M., Marshall samples are prepared and the behavior of the mixes studied. This article reports only on the degradation portion of the study.

Although degradation studies were performed on continuous and skip gradings by earlier investigators, semigap gradings were not studied along with these gradings. Hence, semigap gradings are included in this study.

Certain other related aspects of degradation were not seriously discussed or emphasized in earlier investigations. These include the effect of the pattern of the grading and the method of representing degradation on the degradation of aggregate gradings and the importance of using an appropriate method to represent degradation. Hence these aspects are also discussed in this study.

EXPERIMENTAL PROCEDURE

Selection of Equipment, Number of Balls, and Revolutions

Compared with the results of many standard physical tests used to find out the suitability of aggregates for pavement construction, the results of the Los Angeles method have correlated very well with the performance of aggregates in the field (*1–3*).

Encouraged by the results of the L.A.M., several investigators (*4–6*) modified its standard procedure for different purposes.

As done by other investigators, in the present investigation the Los Angeles method is modified by changing the gradings, number of balls, and number of revolutions used in the standard procedure. In the present investigation the selected gradings were degraded by using six balls and rotating the drum for 100, 175, 250, 500, and 1,000 revolutions.

The number of balls and of revolutions was decided while keeping in mind the rate and amount of degradation of dense gradings in the field, as reported in the study by Goode and Owings (*7*). In their work they studied the degradation of few gradings in the field. Depending on the type of grading, aggregate, and base of pavement (rigid or flexible), the degradation (expressed as a percent increase in fine aggregate, adopted in the present investigation) ranged from 3 to 9 percent over a period of 4 to 10 yr. Taking the degradation as about 6 percent over 7 yr, the degradation of dense gradings may be about 25 percent over a period of 25 to 30 yr, which can be considered the life of bituminous concrete pavements that are properly maintained. In the preliminary studies performed on 20-mm, maximum size Fuller's grading (20 F grading), using three and six balls, it was found that a degradation of 25 percent was obtained at 500 revolutions, when six balls were used. Further, the rate of change of degradation was reason-

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B. Subramanyam, Department of Civil Engineering, S. V. University College of Engineering, Tirupati-517 502 (A.P.), India. Current affiliation: Department of Sanitary Engineering, Water Technology Institute, Arba Minch (AWTI), Ethiopia. M. P. Pratapa, Department of Civil Engineering, S. V. University College of Engineering, Tirupati-517 502 (A.P.), India.

able when six balls were used. To study the degradation of dense gradings further, from an academic point of view, it was decided to perform the degradation up to 1,000 revolutions. Thus on a rough basis the number of balls and the number of revolutions were decided for degrading the selected gradings.

Materials

River gravel, fine aggregate, and filler were all obtained from the same river bed near Kodur, 50 km from Tirupati. The engineering properties of these materials are given in Table 1.

Gradings Selected

Ten entirely different dense gradings, theoretical and practical gradings used in different countries, in three maximum sizes (25 mm, 20 mm, and 12.5 mm) were chosen for the study. These are three theoretical continuous gradings in three maximum sizes (25 F, 20 F, and 12.5 F), two 20-mm maximum size practical continuous gradings (20 IV B and 20 M), three skip gradings (25 S, 20 S, and 12.5 S), and two semigap gradings (25 S.G. and 12.5 S.G.). These gradings are given in Table 2 and Figures 1, 2, and 3.

TABLE 1 PROPERTIES OF MATERIALS

Property	Value
Coarse Aggregate	
Impact value	5.28%
Crushing value	14.71%
Los Angeles abrasion value (B grading)	16.58%
Water absorption	0.62%
Specific Gravity	
Coarse aggregate	2.635
Fine aggregate	2.728
Filler (natural aggregate dust)	2.681

Degrading the Selected Gradings

The material obtained from the river bed was separated into the required sizes; the fractions above 0.30 mm were cleaned with water, air dried, oven dried at 105°C, and stored in separate tins. As the degradation of dense gradings is minimal, the fractions less than 10 mm were separated using a gyratory sieve shaker for 25 min. The set of sieves used for separating the fractions before and after degradation is given in Table 2.

The selected gradings were degraded in the L.A.M. by taking a 5,000-g sample of the initial grading with six balls

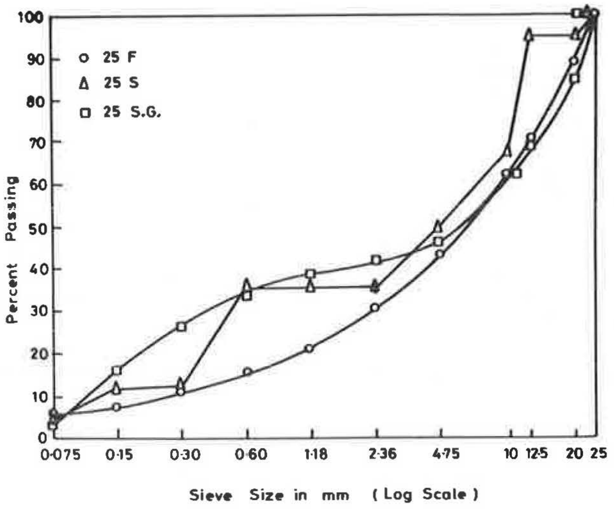

FIGURE 1 25 mm maximum size gradings.

TABLE 2 SELECTED DENSE GRADINGS

Sieve Size (mm)	Percent Passing (by weight)									
	Fuller's Gradings[a]			Skip Gradings[c]			Semigap Gradings		Practical Continuous Gradings	
	25 F[b]	20 F	12.5 F	25 S	20 S	12.5 S	25 S.G.[d]	12.5 S.G.[e]	20 IV B[f]	20 M[g]
25.0	100.0			100			100.0			
20.0	89.4	100.0		95	100		85.0		100.0	100
12.5	70.7	79.0	100.0	95	95	100.0	70.0	100	90.0	90
10.0	63.2	70.7	89.5	68	95	95.0	62.5	82	80.0	84
4.75	43.6	48.7	61.6	50	59	70.0	46.5	53	60.0	74
2.36	30.7	34.3	43.4	36	43	49.5	42.0	44	42.5	65
1.18	21.7	24.3	30.7	36	43	49.5	39.0	42	33.0	56
0.60	15.5	17.3	21.9	36	43	49.5	35.0	39	23.5	40
0.30	10.9	12.2	15.5	12	13	15.0	26.0	31	18.0	20
0.15	7.8	8.7	10.9	12	13	15.0	16.0	14	12.0	7
0.075	5.5	6.1	7.8	5	6	6.0	4.0	5	7.0	3

[a] Formula $P = 100\,(d/D)^{0.5}$ in which P = total percentage passing given sieve; d = size of sieve opening; and D = largest size (sieve opening) in gradation.
[b] 25 mm maximum size Fuller's grading (similarly other gradings, also; number representing maximum size of the grading and the letter representing type).
[c] Adopted from ASTM (*8*) gradings.
[d] Marais (*9*).
[e] Barder Greene Co. (*10*), Michigan State grading.
[f] The Asphalt Institute (*11*) IV B grading.
[g] Goode and Owings (*7*), adopted grading from the plotted graph of Maryland grading.

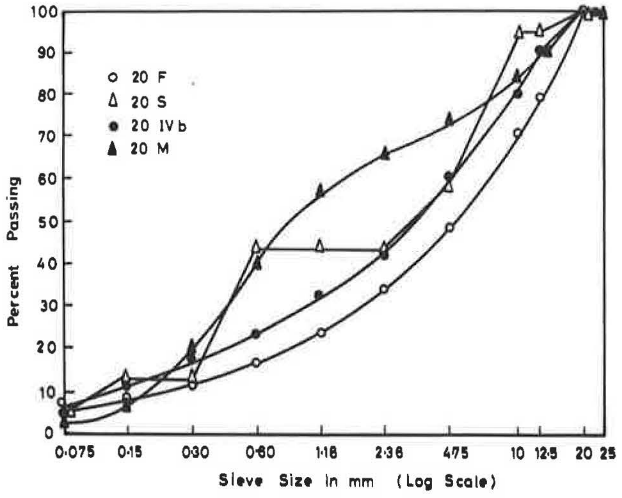

FIGURE 2 20 mm maximum size gradings.

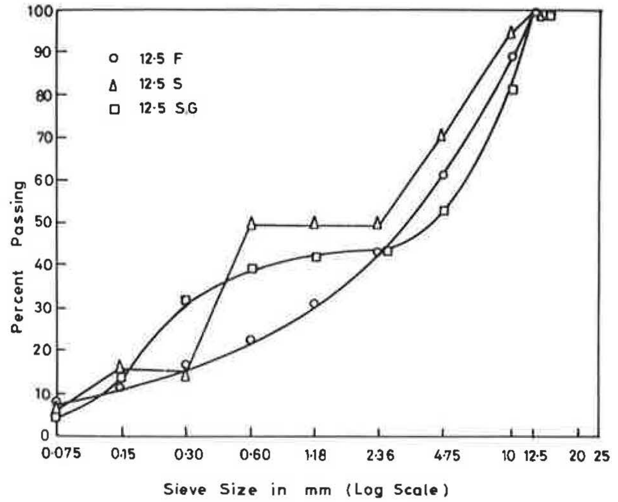

FIGURE 3 12.5 mm maximum size gradings.

TABLE 3 SURFACE AREA FACTORS FOR DIFFERENT AGGREGATE SIZES

Sieve Size (mm)		Surface Area
Passing	Retained	Factors[a] (cm²/g)
25	20	1.1[b]
20	12.5	1.62[c]
12.5	10	2.29[c]
10	4.75	4.0
4.75	2.36	6.3
2.36	1.18	12.7
1.18	0.60	18.9
0.60	0.30	30.0
0.30	0.15	100.0
0.15	0.075	205.0
0.075	Pan	615.0

[a] Assumed specific gravity = 2.65. For values other than 2.65, multiply the above factors by 2.65/sp.gr. Adopted from Ramana Sastry and Rao (*6*).

[b] Adopted from Dunn (*12*).

[c] Adopted from Somayajulu (*13*).

and rotating the drum up to 100, 175, 250, 500, and 1,000 revolutions. As the degradation of a dense graded material is very small, utmost care was taken in sieving the degraded material.

OBSERVATIONS AND ANALYSIS OF TEST RESULTS

Representation of Degradation

Several methods have been used by various investigators to represent degradation. Each method has its own advantages and disadvantages. No method is effective in all situations. So either a general method, such as the surface area method, or one appropriate to a particular study or some arbitrary method has been used in earlier research.

The degradation of the selected dense gradings is expressed by three methods—percent increase in surface area (calculated using surface area factors given in Table 3), percent increase in filler (material passing a 0.075-mm sieve), and percent increase in fine aggregate (material passing a 2.36-mm sieve and retained on a 0.075-mm sieve)—that are appropriate in this method. The values are given in Table 4. The values obtained by the percent increase in fine aggregate method (adopted in this study) are also shown in Figure 4. To give an idea of the degradation of gradings at different revolutions, the degradation of 25 S and 12.5 S.G. gradings is also shown by grain-size distribution curves at 175, 500, and 1,000 revolutions in Figures 5 and 6, respectively. As the curves come very close, the degradation at 100 and 250 revolutions is avoided.

Effect of Method on Degradation

The values given in Table 4 show that the amount of degradation at the same number of revolutions is not the same with all the methods, even though the amount of breaking of the particles of a grading is the same at the same number of revolutions. This indicates the effect of the method on the amount of degradation.

Further, when the degradation is expressed by different methods, the order of the gradings from a degradation point of view also changes, as can be observed from the values shown in Table 4. This is due to the difference in the development of varying amounts of surface area, filler, and fine aggregate in different gradings. The order of the gradings in different methods is given below (maximum degradation first). In deciding this order the degradation of the gradings at 500 and 1,000 revolutions is given more importance, as at lesser revolutions the values are contradictory for some gradings because of experimental limitations.

Method of Degradation	*Order of the Gradings*
Percent increase in surface area	25 F, 25 S, 20 F, 20 M, 25 S.G., 20 S, 12.5 S.G., 12.5 F, 20 IV B, and 12.5 S.
Percent increase in filler	25 S.G., 20 M, 12.5 S.G., 25 S, 25 F, 20 F, 20 S, 12.5 S, 20 IV B, and 12.5 F.
Percent increase in fine aggregate	25 F, 20 F, 12.5 F, 20 S, 12.5 S, 20 IV B, 25 S, 12.5 S.G., 20 M, and 25 S.G.

TABLE 4 DEGRADATION OF THE SELECTED GRADINGS EXPRESSED BY DIFFERENT METHODS

Method of Degradation (% Increase over Original) (1)	Degradation at Different Revolutions of L.A.M.				
	100 Rev (2)	175 Rev (3)	250 Rev (4)	500 Rev (5)	1,000 Rev (6)
25 F Grading					
Surface area	11.0	23.2	31.9	66.4	123.5
Filler	11.1	25.9	36.9	77.0	146.5
Fine aggregate	8.3	14.2	16.9	28.4	52.4
20 F Grading					
Surface area	11.1	21.0	29.9	59.9	113.8
Filler	12.1	23.9	34.5	71.4	139.5
Fine aggregate	6.4	10.8	14.2	26.8	46.2
12.5 F Grading					
Surface area	6.1	14.4	21.0	41.2	72.4
Filler	6.6	15.9	24.4	49.5	85.5
Fine aggregate	5.4	9.5	12.3	23.3	45.1
25 S Grading					
Surface area	12.3	22.2	32.1	59.9	116.7
Filler	14.8	28.0	43.0	88.8	176.8
Fine aggregate	6.0	9.8	12.1	20.7	37.0
20 S Grading					
Surface area	5.3	14.0	20.2	46.1	82.3
Filler	5.1	13.7	22.3	60.3	112.0
Fine aggregate	4.6	10.4	14.6	23.9	40.3
12.5 S Grading					
Surface area	7.0	12.5	18.5	35.8	68.5
Filler	7.7	14.8	24.0	49.2	102.0
Fine aggregate	7.3	11.3	14.0	24.1	36.4
20 IV B Grading					
Surface area	6.0	13.4	19.2	26.7	73.0
Filler	6.8	15.3	22.7	44.0	94.9
Fine aggregate	5.7	9.8	12.8	23.0	35.9
20 M Grading					
Surface area	17.1	24.3	33.4	58.9	101.3
Filler	36.7	52.7	72.0	125.3	218.0
Fine aggregate	0.8	1.8	2.8	6.1	10.6
25 S.G. Grading					
Surface area	15.9	22.6	30.5	52.5	95.2
Filler	42.5	55.5	73.5	125.0	225.5
Fine aggregate	0.5	1.0	2.6	5.2	11.2
12.5 S.G. Grading					
Surface area	11.8	18.4	27.0	47.2	77.4
Filler	22.2	35.0	55.4	93.6	160.8
Fine aggregate	2.8	5.5	6.3	13.9	25.7

It is interesting to see that the 25 S.G. grading is the least degraded one when expressed by percent increase in fine aggregate method; when expressed by the percent increase in filler method, however, the same grading is the most highly degraded one.

Thus because the degradation of gradings and the order of the gradings are not the same, it is necessary that an appropriate method be selected when degradation is expressed by different methods. Otherwise, a wrong decision may be made in selecting or placing the gradings in the order of preference from a degradation point of view.

Selection of the Appropriate Method

Degradation has an effect on the performance of the product in which it takes place. It is mainly for this reason that degradation studies are performed. Thus, a method of degradation whose values have a bearing on the performance of the product in which it takes place should be selected to represent degradation. Collett et al. (*14*), Dunn (*12*), and others studied the degradation of base course aggregates and expressed degradation as the percent increase in the material passing a 0.075-mm sieve, as it is this material that affects the stability of the base course when it gets mixed with subsurface water.

From this point of view the effects of the surface area of the grading, the filler content, and the fine aggregate content on mix properties are examined here to decide the suitable method to represent degradation.

In Table 5 the total surface area of the grading, surface area of the filler in the grading, and surface area of the grading excluding filler are shown for the original grading and for that developed after 1,000 revolutions for 12.5 F grading. These values are 6542, 4705, 1837 and 11276, 8717, 2557 sq cm/100 g for the respective gradings. These values show that the

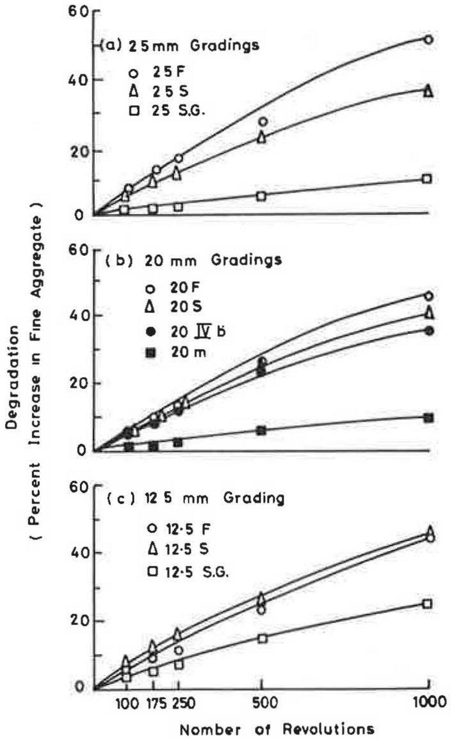

FIGURE 4 Degradation of selected dense gradings.

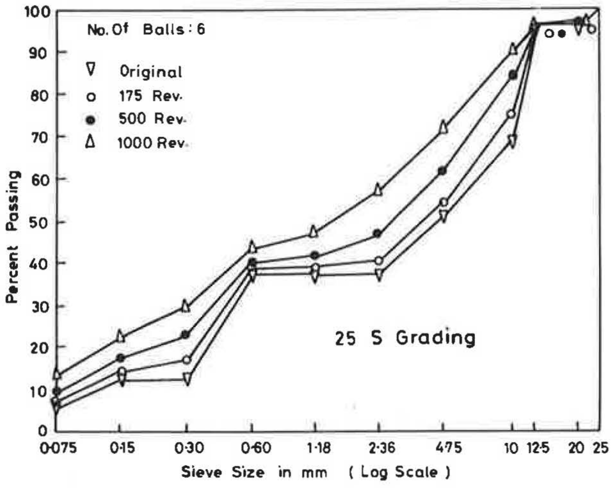

FIGURE 5 Degradation of 25 S grading at different revolutions.

greatest part of the surface area of the grading is contributed by the filler content alone. In other words the degradation expressed as the percent increase in surface area is more or less the same as that expressed in terms of the percent increase of filler content. This is evident in the case of most of the dense gradings, as can be seen from the values shown in Table 4. Hence, if the properties of the bituminous concrete mixes are shown to be affected by degradation expressed by percent increase in surface area, it also amounts to saying that the mix properties are affected by a change in filler content.

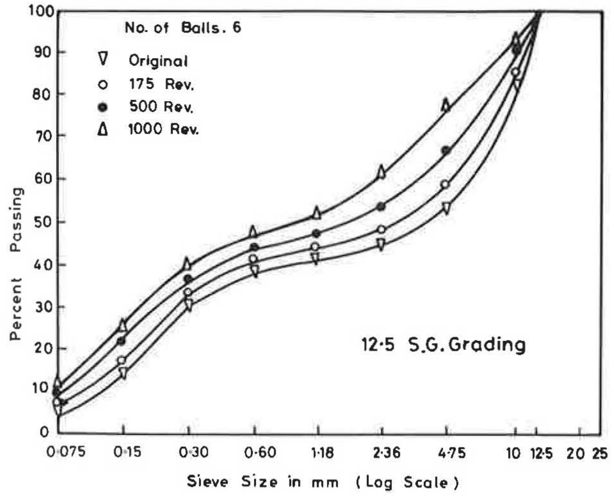

FIGURE 6 Degradation of 12.5 S.G. grading at different revolutions.

TABLE 5 INFLUENCE OF FILLER ON THE SURFACE AREA OF A GRADING (12.5 F GRADING)

	Grading	
	Original	At 1,000 Revolutions
Total surface area (cm²/100 g of the grading)	6,542	11,276
Surface area of the filler portion only (cm²)	4,705	8,717
Surface area of the grading leaving filler (cm²)	1,837	2,557

Campen et al. (*15*), who studied the mix properties in relation to the surface area of the gradings, concluded that the minimum voids in the aggregate do not indicate the surface area of the aggregate and that the asphalt requirement is not directly proportional to the surface area. Further, Lefebvre (*16*), who studied the effect of type and amount of coarse aggregate, fine aggregate, fine sand in fine aggregate, and filler on the Marshall properties, concluded that the type and amount of fine aggregate have a more pronounced effect on such important properties as stability, voids in mineral aggregate, and air voids in the mixes. Shklarsky and Liveneh (*17*) conducted extensive studies on the effect of fine aggregate on bituminous mixes; they concluded that the influence of fine aggregate in the gradation in question is decisive.

To prove the greater influence of fine aggregate over surface area or filler content on mix properties, Marshall stability values are plotted at various levels of degradation expressed by the three methods in Figure 7. In the figure the degradation shown is the total of the degradation at any specified number of revolutions in the L.A.M. and the degradation taking place in the Marshall mold because of compaction when the specimens are prepared. The curves show that for a certain amount of rise or fall in stability, the change required in the amount of fine aggregate is less than that of the surface area or filler content. This means that the stability is more sensitive to

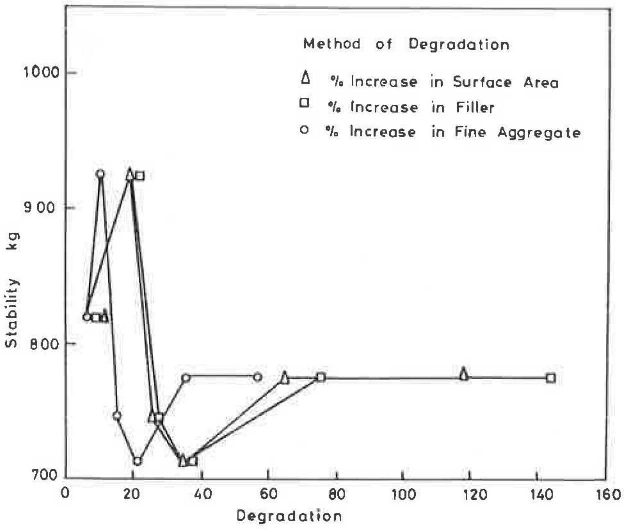

FIGURE 7 Effect of degradation on stability.

variation in fine aggregate than in surface area or filler content. The same thing holds true for other mix properties and also in the case of other gradings.

From the preceding observations, it becomes clear that the mix properties are more sensitive to variation in fine aggregate than to surface area or filler; hence, expressing degradation by percent increase in fine aggregate is more appropriate than by percent increase in surface area of the grading or by percent increase in filler content. This method is also direct and simpler, and degradation curves drawn by this method are also smooth, as can be seen in Figure 4.

Degradation of the Selected Gradings

On the basis of the degradation that occurred on the selected dense gradings, the following observations are made.

1. The systematic upward shift of the degradation curves (Figure 5 and 6) shows that the pattern of degradation is unique and is the same whatever the type of grading. Further, the degradation curves in Figure 4 show that the degradation is a systematically increasing one, the rate of increase declining with the increase in the repetition of the same load. This shows that as the degradation continues, the gradings become rich in fine aggregate and the amount of degradation decreases. From this it can be inferred that fine aggregate content increases in gradings of the same maximum size; the degradation decreases. This must be due to the cushioning effect of the increased fine aggregate and filler and the decrease in coarse aggregate.
2. In the case of skip gradings, the gaps get covered because of degradation, and this coverage is systematic; and if the degradation is continued, the skip gradings become continuous gradings with increased fine aggregate and filler (Figure 5).
3. From a degradation point of view the order of the gradings in a decreasing order of degradation is as follows:
   a. Order of the gradings in the same maximum size:

25-mm gradings	25 F, 25 S, 25 S.G.
20-mm grading	20 F, 20 S, 20 IV B, 20 M
12.5-mm grading	12.5 F, 12.5 S, 12.5 S.G.

   b. Order of the gradings in the same group:

Fuller's gradings	25 F, 20 F, 12.5 F
Skip gradings	20 S, 12.5 S, 25 S
Semigap gradings	12.5 S.G., 25 S.G.
Practical continuous gradings	20 IV B, 20 M

   c. Order of the gradings when all the gradings are considered:
   25 F, 20 F, 12.5 F, 20 S, 12.5 S, 20 IV B, 25 S, 12.5 S.G., 20 M, and 25 S.G.

From the preceding orders the following conclusions can be drawn:

1. Within the same maximum size gradings Fuller's gradings degraded the most, followed by skip and either practical continuous gradings such as 20 IV B or 20 M or semigap gradings. This must mainly be due to a lesser amount of fine aggregate and filler in Fuller's gradings when compared with other gradings.
2. Within the same group of gradings, the degradation of Fuller's gradings followed a definite pattern. In these gradings, as the maximum size decreased, the degradation also decreased. But the same trend is not observed with skip or semigap gradings. This is because these gradings are not derived by the same procedure as Fuller's gradings and because of their pattern. In the case of skip gradings the higher maximum size skip grading (25 S grading) degraded less than the other two lower maximum sizes. This is because of the missing 20-mm to 12.5-mm fraction in the coarser portion of the 25 S grading. Such a large gap in the coarser portion is not present in the other two smaller, maximum size skip gradings. Because of this gap, the fraction above the gap (i.e., 25-mm to 20-mm size fraction), first degraded to 20-mm and 12.5-mm size in greater amounts before it broke further into still smaller sizes. Thus the pattern of 25 S grading made it degrade less. In the case of semigap gradings, although the amount of fine aggregate and filler, which gives cushioning effect, is almost the same (42 percent in the 25 S.G. grading and 44 percent in the 12.5 S.G. grading), the lower maximum size 12.5 S.G. grading degraded more than the higher maximum size 25 S.G. grading. This again is due to the pattern of these two gradings (Figures 1 and 3).

Thus the general observation normally made that the degradation reduces as the maximum size of the gradings decreases may hold true when gradings of different maximum sizes are derived by the same procedure, as observed with Fuller's gradings. Otherwise, it is the pattern of the gradings that controls their degradation. So, one should not be misguided by the mere mention of the maximum size of the gradings while considering the gradings from a degradation point of view.

The effect of the pattern of the gradings can also be observed in the case of gradings of the same maximum size. Although the amount of fine aggregate and filler content of 12.5 F and 12.5 S.G. gradings is almost the same (about 44 percent), 12.5 F grading degraded more than 12.5 S.G. grading.

3. Among the various gradings studied semigap gradings and 20 M grading with 65 percent fine aggregate and filler degraded less. This may perhaps be one of the reasons for the greater durability of pavements constructed with semigap

graded mixes compared with the continuous graded mixes of the 20 IV B type of grading.

CONCLUSIONS

From the preceding observations and discussion, the following conclusions are drawn.

1. The amount of degradation of aggregate gradings depends on the method used to express it. The order of the gradings, from the degradation point of view, changes with the change in methods adopted to express degradation.
2. In expressing degradation, a method whose values have a bearing on the performance of the product in which it takes place should be used. In the case of dense gradings, it is more appropriate to represent degradation by the percent increase in fine aggregate than the percent increase in surface area or filler, as the mix properties are more sensitive to variation in fine aggregate content.
3. The maximum size of the gradings does not alone decide the degradation of gradings. The pattern of the gradings is also important.
4. The order of the selected gradings, in decreasing order of degradation, is 25 F, 20 F, 12.5 F, 20 S, 12.5 S, 20 IV B, 25 S, 12.5 S.G., 20 M, and 25 S.G.; 25 F is degrading maximum.

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