CONSIDERATION OF PARTICLE ORIENTATION IN THE COMPACTION OF ASPHALT CONCRETE

William D. O. Paterson, National Institute for Road Research, Pretoria, South Africa

ABRIDGMENT

•WHEN a bituminous mixture deforms under load, as during compaction, changes occur in its internal structure. The initial structure of irregularly shaped solid particles randomly oriented and distributed is shaped into a structure with definite characteristics of packing and orientation. Analysis of the system of stresses and the transfer of energies shows that the particles are likely to be moved into a generally parallel orientation perpendicular to the principal imposed stress (1). This ultimate structure will be in a stable energy state and will be able to sustain the imposed traffic stresses without permanent deformation.

The 2 components of changes in internal structure are translation and rotation. The rotation or reorientation component has a significant effect on mixture strength. It is much smaller than the translation component in mixtures of near-spherical or cubical particles and in some uniform or 1-size mixtures, such as a sand-asphalt. But, in a dense-graded mixture, it is highly significant. Few quantitative studies have been reported of this topic (2), and thus an attempt is made here to assess the significance and contribution of particle orientation in dense-graded mixtures. A more detailed report is also available (1).

INVESTIGATION

During an investigation of traffic compaction in dense-graded mixtures we made measurements of particle orientation to determine the changes occurring during trafficking. Trafficking was full-scale and controlled in 2 levels of tire contact pressure (280.620 kPa) and 2 of mixture temperature (25 and 40 C) (3). The mixes were of 1 dense gradation of an aggregate with low flakiness and nominal maximum size of 16 mm. Binder viscosity, binder content, and initial density were varied. The thickness was 50 mm. Compaction was done by pneumatic rollers.

The orientation of individual particles was measured graphically from photographs made of thin strips cut from a block taken from the pavement as shown in Figure 1. Coordinate measurements of the end points of each particle were recorded. Orientation was the direction of the longest dimension on the projection. The data were subjected to the Tukey chi-square (x^2) statistical analysis (4) in groups by particle length, depth, and region and in toto for each sample.

DISCUSSION OF RESULTS

Analysis of the data typically yielded distributions as shown in Figure 2 for the before and after trafficking states. The distributions are shown in the polar form common in geological applications with discrete ranges of 10 deg as used in the statistical analysis. Visual comparison with a random distribution indicates a high degree of preferred orientation.

The results of the statistical analyses are summarized in Table 1. These show that the aggregate particles did exhibit a preferred orientation in the range of 3 to 8 deg from the horizontal rather than in a random manner. This was demonstrated by the chi-square test, which indicated that there was less than 0.5 percent significance

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Figure 1. Typical specimen for orientation analysis.

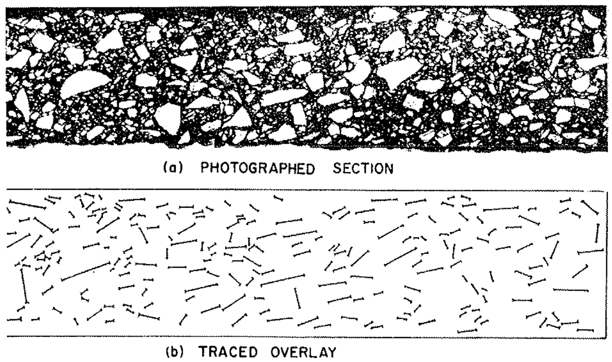


Figure 2. Typical polar distributions of orientation.

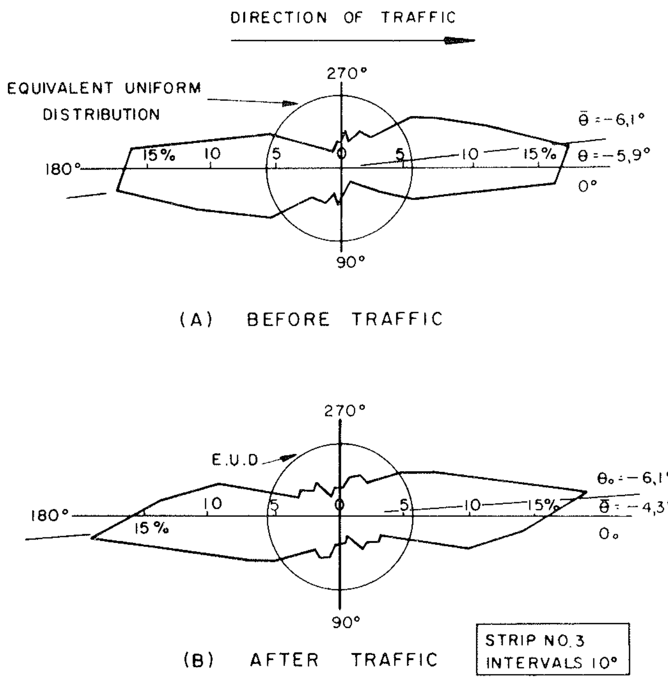


Table 1. Summary of particle orientation analysis.

Strip Number	Bitumen: Content (percent)	Bitumen: Viscosity (m^2/s at 40 C)	Initial Density (percent 2 × 75-blow)	Traffic	Orientation (degrees): Mean	Orientation (degrees): Preferred	Probability of Being Within 10 Deg of Mean	x^2	Sample Size
1	6.1 (optimum)	2.0	98	Before	-3.6	-5.1	0.326	553	920
				After	-3.1	-4.4	0.298	334	786
2	6.1 (optimum)	2.0	95	Before	-7.3	-8.1	0.321	356	586
				After	-3.1	-7.2	0.274	46	494
3	6.8 (excess)[a]	2.0	98	Before	-6.1	-5.9	0.341	594	986
				After	-4.3	-6.1	0.354	420	822
4	6.1 (optimum)	0.50	98	Before	-2.8	-6.4	0.288	432	1,118
				After	-5.5	-8.6	0.291	553	1,268
5	5.2 (deficient)	0.50	98	Before	-5.1	-7.4	0.328	744	1,549
				After	-5.4	-7.5	0.298	543	1,311

Note: For particles with a projection >2 mm only.

[a]With respect to design.

Table 2. Subanalysis of orientation by size, depth, and region for strip 1.

Item	Massed Data	By Particle Size[a]: 1 to 3 mm	3 to 6 mm	6 to 12 mm	>12 mm	By Depth in Pavement[b]: 0 to 13 mm	13 to 25 mm	25 to 38 mm	38 to 50 mm	By Regions Along Block[c]: 0 to 100 mm	100 to 200 mm	200 to 300 mm	300 to 400 mm
Before Traffic													
Preferred orientation, degrees	-5.1	-6.0	-5.3	-4.2	-4.8	-10.3	-4.6	-5.3	-2.5	-2.5	-4.1	-6.9	-8.7
Sample size	920	257	480	211	25	203	226	237	208	257	245	230	188
x^2	553	130	258	161	16	124	130	128	130	153	128	164	93
Probability of occurrence, degrees	0.326	0.327	0.308	0.379	0.320	0.281	0.301	0.312	0.313	0.327	0.355	0.309	0.261
After Traffic													
Preferred orientation, degrees	-4.4	-2.8	-3.6	-5.0	-9.9	-10.4	-5.0	-5.4	-3.2	-6.0	-5.9	+1.6	-5.2
Sample size	786	334	347	196	27	150	154	176	190	194	209	190	198
x^2	334	99	172	77	10	46	66	69	104	65	95	94	120
Probability of occurrence, degrees	0.298	0.269	0.343	0.240	0.370	0.254	0.326	0.270	0.250	0.280	0.325	0.303	0.308

[a]Range of exposed length. [b]From the surface. [c]From leading edge.

of random orientation, that is, the particles had a preferential orientation. The slight differences that could be noticed between the arithmetical mean orientations and the preferred orientations occurred when the distributions exhibited a smaller ill-defined peak in addition to the dominant peak. The dispersion of the distribution is given as the probability, P, of the orientation of a particle being within 10 deg of the mean, the probability of occurrence.

A comparison of the results of strips 1 and 2 indicates the effect of construction density for a normally designed mix with 80-100 penetration grade bitumen. Before trafficking, the highly compacted mix had a lower mean orientation (3.6 deg) than the lightly compacted mix (7.3 deg); after trafficking these were both reduced to 3.1 deg. Higher compactive effort seems to result in flattening the particles to a more horizontal position.

The effect of excess binder in a mix may be assessed by comparing the rich mix on strip 3 to the normal mix on strip 1. Although the mean orientation was slightly higher for the rich mix, the probability of occurrence was higher than that for the normal mix (0.341 versus 0.326) and increased further under traffic (0.354). This illustrates the more fluid nature of the rich mix, which allows easier manipulation of individual particles into their stable positions.

The effect of binder viscosity may be assessed by comparing the soft mix on strip 4 and the hard mix on strip 1. In the soft mix contrary characteristics are evident with the mean orientation increasing slightly and the probability of occurrence being low at 0.29.

The size, depth, and regional location of particles had the effects on orientation given in Table 2 for strip 1. Size appears to have negligible influence because there is no consistent trend in most parameters except a slight maximum for 3- to 6-mm length in the χ^2 value. Depth within the layer does appear to have an influence on orientation but its extent is masked in the most critical regions, such as near interfaces, because there the orientation is dictated by the nearest particle face rather than by the longest dimension adopted by definition. The analysis by regional location is a measure of the variation to be expected between similar subgroups and is thus an indication of the significance of the overall result. From the final panel of Table 2 it can be seen that the mean and preferred orientations vary by ±3 deg and the probabilities of occurrence by ±0.02 deg.

In the light of these naturally occurring variations it is apparent that the changes in orientation under traffic compaction and the differences due to subsidiary factors of mix design and construction conditions have a very low significance.

PRACTICAL IMPLICATIONS OF RESULTS

The significant degree of preferred orientation achieved under rolling compaction has important implications. The stability of a field core cut from a pavement was generally much lower than that of a block of the same mix molded in the laboratory by impact compaction to the same density conditions as shown in Figure 3. Little of the difference was attributable to mixing variations and most of it was due to differences in particle orientation. The rolling compaction in the field produced a preferentially horizontal orientation that was weak in the horizontal plane but strong in the vertical. Impact compaction however causes more wedging than alignment and in addition there is the perpendicular alignment due to the sidewall effects of the mold, which increase the strength in the diametral plane.

Another phenomenon is the effect that the constructed density had on the final density of a bituminous surfacing. Figure 4 shows the data for several mixes. If the initial structure had no influence on the final structure the curves would have zero gradient but the gradient is generally positive. In other words, normal traffic alone is insufficient to develop the same internal structure as developed by construction rollers, that is, the same arrangement of orientation and packing. At high mix temperatures this phenomenon becomes much less significant.

Figure 3. Influence of compaction mode on Marshall stability.

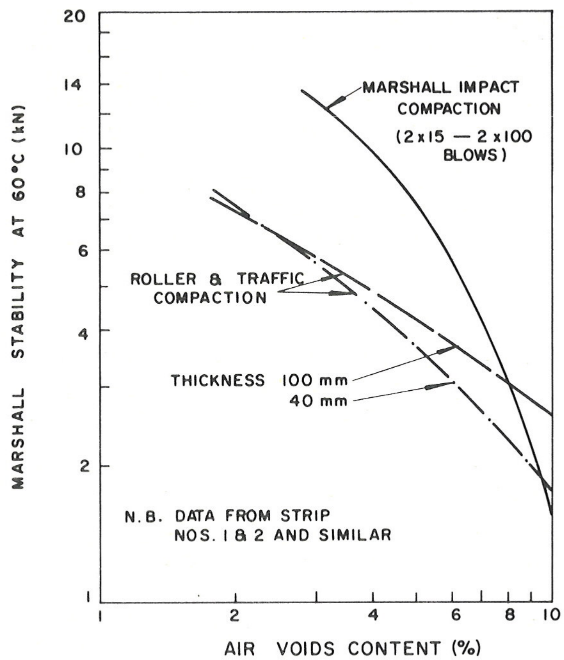
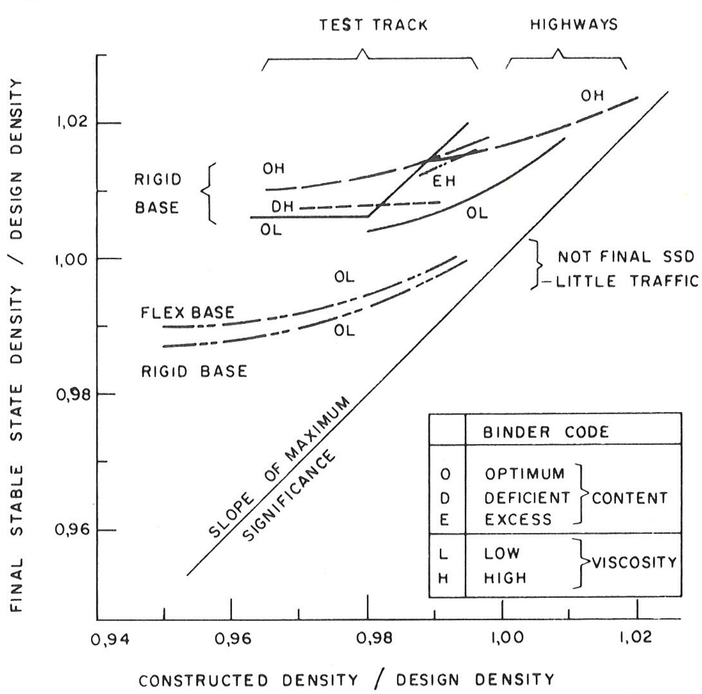


Figure 4. Influence of constructed density on final stable state density.



CONCLUSIONS

Measurements on dense-graded asphalt concrete samples cut from a pavement showed that approximately 30 percent of the particles were oriented at angles within 10 deg of the preferred orientation and that the preferred orientation was generally in the range 4 to 8 deg above the horizontal in the direction of trafficking. Small changes were apparent under the compacting effect of simulated traffic but these were barely significant statistically. Low viscosity and high binder content appeared to promote preferential orientation but, again, the differences were not statistically significant. Particle size had negligible influence. The structural properties of a mix are very sensitive to orientation characteristics. Reorientation appears to be a function primarily of viscous resistance in the binder; changes in packing density are more a function of aggregate characteristics.

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