Aggregate Type and Traffic Volume as Controlling Factors in Bituminous Pavement Friction

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The New York State Department of Transportation's (NYSDOT's) Pavement Friction Inventory program has collected friction data on 155 pavement sites since testing began in 1980. The data gathered were analyzed and the adequacy of the current high-friction aggregate specification, in place since 1970, was determined. Data from another 66 sites, gathered as part of a previous NYSDOT study, were included. Together, the 221 sites tested represent most combinations of coarse aggregate rock types and traffic volumes normally encountered in New York State. The coefficient of friction for a pavement at terminal polish, as determined by a drag-force trailer in accordance with ASTM E274, was found to be controlled mostly by coarse aggregate rock type and daily traffic volume, expressed as lane average annual daily traffic (LAADT). Mineral aggregates used in New York State were divided into three rock-type categories—homogeneous, sandy, and blended—each having a distinct polishing mode. Semilog plots of friction number versus LAADT were constructed for each rock type, showing whether each rock type is performing adequately and, if not, under what traffic conditions its use must be restricted.

The purpose of the study reported here was to analyze pavement friction data and determine the adequacy of New York's current high-friction aggregate specification. Data from 155 pavement sites were gathered as part of an ongoing Pavement Friction Inventory (PFI) program administered by the Materials Bureau of the New York State Department of Transportation (NYSDOT). Data from another 66 sites had been gathered previously by the NYSDOT Engineering Research and Development Bureau and were included in the analysis.

Friction properties of bituminous pavement surfaces were derived from their macro- and microtextural roughness. Macrotexture is roughness due to aggregate size, shape, and gradation. Microtexture [which depends on the petrology or rock physical characteristics of exposed individual particles (*1–4*)] and the lane average annual daily traffic (LAADT) have been good predictors of pavement friction (*5,6*). NYSDOT has relied on a high-friction aggregate (HFA) specification (given later in the paper) that defines which aggregates are to be used in terms of rock type, acid-insoluble residue (AIR) content, and minimum blending percentages. The department's PFI program monitors performance of aggregates meeting the HFA specification, using a matrix of aggregate rock types and daily traffic volumes as encountered throughout the state (Table 1).

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SITE SELECTION AND FRICTION MEASUREMENT

The PFI was established in 1978 in response to a Federal Highway Administration requirement to monitor pavement friction performance. NYSDOT's monitoring program is based on testing pavement sections representative of highway construction throughout the state. Selection of a PFI site involves field evaluation of potential sections, pavement coring, and petrographic analysis of aggregate extracted from these cores to determine proportions of the various rock types present in the coarse fraction. Field evaluation avoids any pavement having problems that might affect friction measurements, such as flushing or raveling. Also, close examination of the pavement flushing indicates whether aggregates are uniformly distributed throughout the potential test section. Depending on the HFA type used, petrographic analysis includes appropriate determinations of constituent rock types, percentage of noncarbonate materials in blended aggregate, and AIR. Acceptable test sites are fitted into the inventory matrix according to their aggregate classification and LAADT, as indicated in Table 1. All PFI sites have been and will continue to be scrutinized in this manner.

All friction testing is performed with the NYSDOT two-wheeled drag-force trailer, using a procedure conforming to ASTM E274 with a standard ribbed test tire (ASTM E249). Tests are run at 64 kph (40 mph) and 89 kph (55 mph) on roughly tangent pavement sections over a distance of 0.48 km (0.3 mi). The department considers paving materials and surface texture to be adequate when measured friction number (FN) [wet at 64 kph (40 mph)] is 32 or higher. This number was selected as a minimum design target value because it corresponds to the friction assumed by AASHTO in calculating stopping distances.

AGGREGATE CATEGORIES

Aggregates may be separated into three categories on the basis of their polishing characteristics: homogeneous, sandy, and blended (Table 1). Each responds to traffic wear in its own way.

Homogeneous Rock Types

Homogeneous rock types contain mineral constituents having roughly the same Moh's hardness (a scratch hardness rating

TABLE 1 Sites in the PFI Matrix

	Lane AADT					
Aggregate Type	-1K	1K-2K	2K-5K	5K-10K	10K-20K	20K-30K
HOMOGENEOUS						
Traprock	0	3	1	2	2	2
Granite	5	1	1*	0*	0*	0*
Limestone						
Dolomite						
Wappinger	0	2	2	2	2	1
Lockport	2	7	9	1	0*	0*
Other	3	2	2	0	0	0
SANDY						
Sandstone	3	6	6	0	0	0
Siliceous Limestone	4	7	3	0*	0*	0*
Siliceous Dolomite	3	4	13	4	2	0*
BLENDS						
Limestone/Non-Carb.	18	21	21	8	4	0*
Dolomite/Non-Carb.	0	o	0	1*	1*	0*
Gravel	2	4	2	0*	0*	0*

*More sites being sought

on a scale of 1 to 10, reflecting a mineral's resistance to wear) and include traprock, granite, limestone, and dolomite. Uniform Moh's hardness results in even particle wear in the pavement surface. The two carbonate rocks included in this category, limestone and dolomite, have low AIRs. Of the two, dolomite is allowed by the current HFA specification to be used alone in top courses in NYSDOT projects. Since the HFA specification does not allow use of limestone alone as the coarse aggregate, no such sites were tested.

Sandy Rock Types

These rock types contain quartz sand either as the major constituent or as a significant component and include sandstone, siltstone, quartzite, siliceous limestone, and siliceous dolomite. The last two are carbonate rocks having high AIRs.

Aggregate Blends

These contain two or more rock types, both carbonate and noncarbonate. Since the noncarbonate rock types capable of meeting NYSDOT quality requirements have Moh's hardnesses much greater than carbonates and are consequently more resistant to wear and polish, they provide most of the friction in these blends.

ANALYSIS OF TEST DATA AND DISCUSSION

Friction of new pavements comes mostly from macrotexture, since the aggregate is still coated with asphalt. As traffic wears the surface, aggregate is exposed and polished. Eventually, all coarse aggregate particles at the surface are abraded to an equilibrium condition referred to as "terminal polish" (*1,2,7*) (Figure 1). It generally takes 2 to 3 years of exposure to traffic before that condition is reached (*5,6*). Testing normally begins on PFI sites 2 or more years after construction, and the data show no decline in FN. A non-PFI site, tested shortly after construction and for the next 2 years because of anticipated inadequate friction performance, showed rapid decline in driving lane friction within the first year (Figure 2). Many sites were tested annually 8 to 10 times, and all were tested at least twice. The data show that FN for any given site fluctuates about an average. Thus, the coefficient of friction for each site is expressed as an arithmetic average of all FN. Only the FNs determined at 64 kph (40 mph) were used in the analysis because they can be related to the established design minimum FN of 32.

Data for each rock type were plotted as average FN at 64 kph (40 mph) versus LAADT on a semilog grid. When all other variables are eliminated, traffic volume shows an inverse relationship to friction in all aggregate categories. Table 2 gives FNs for pavement sites where both driving and passing lanes were tested at terminal polish. When both lanes have the same mix, contain the same aggregates, and are constructed under essentially the same conditions, the only remaining significant variable is traffic volume. Under such conditions, the driving lane, which invariably carries more traffic than the passing lane, always has a lower FN, regardless of aggregate type.

The amount of AIR in a carbonate aggregate and the amount of noncarbonate particles in an aggregate blend are significant factors in pavement friction (7). These considerations were incorporated into the HFA specification tested in this study.

Homogeneous Rock Types

Initial analyses included these aggregates because they involve the fewest variables. In Figure 3 data from sites containing

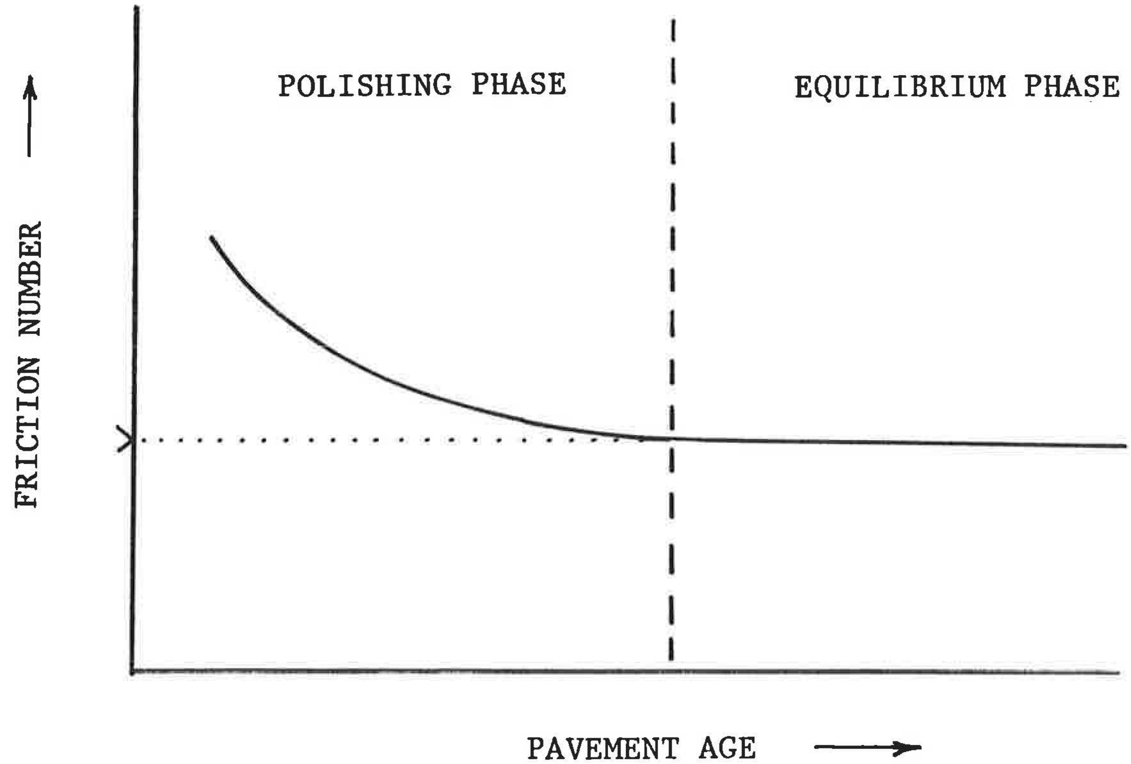

FIGURE 1 Generalized pavement polishing model in which a "terminal polish" condition is reached, first shown in laboratory studies (*1,2*).

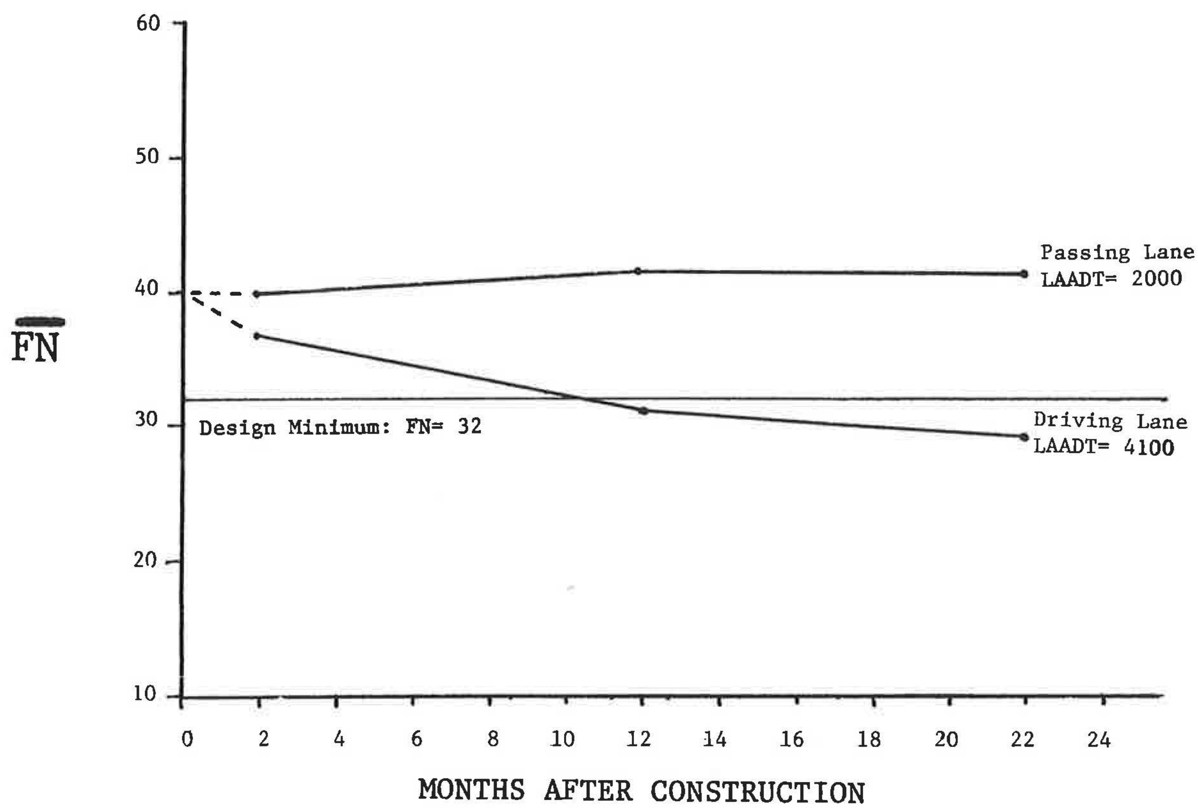

FIGURE 2 Average FN at 64 kph (40 mph) versus LAADT for a pavement made of blended aggregate containing 10 percent noncarbonate particles.

TABLE 2 FNs for Sites Where Driving and Passing Lanes Were Tested

Site	Lane	LAADT	Avg. Friction Number at 64 kph (40 mph)	Coarse Aggregate
A	Driving	3,800	52	Sandstone
	Passing	2,500		
B	Driving	1,700	46	Siliceous Dolomite
	Passing	800	51	(22% AIR)
C	Driving	10,800	42	Siliceous Dolomite
	Passing	6,500	47	(35% AIR)
D	Driving	18,000	28	Blended Aggregate
	Passing	12,200	37	(18% Noncarbonate)
E	Driving	4,100	29	Blended Aggregate
	Passing	2,000	42	(10% Noncarbonate)

traprock were combined with data from sites containing granite, because both rock types have similar Moh's hardnesses (6 to 7) and are made up of interlocking mineral crystals. The data clearly correlate well, with a straight best-fit line showing that 11 FNs are lost for every log-cycle increase in LAADT. A similar plot of sites containing Wappinger dolomite (Figure 4), a nonsiliceous stone quarried extensively in southeastern New York just north of New York City, also shows a good correlation. The best-fit line for the Wappinger dolomite has a negative slope of 18 FNs per cycle. In both plots, lines were drawn parallel to the best-fit lines, above which 90 percent of the data fall. These "90 percent lines" were used to test and predict HFA specification conformance for these aggregates. Figure 3 shows the 90 percent line for traprocks and granites intersecting the "FN 32 design minimum" line at about 33,000 daily vehicle passes, indicating that these aggregates can be expected to provide adequate friction up to that traffic volume. Fortunately, it is unlikely that an LAADT above 33,000 will be encountered in New York State. On the other hand, Figure 4 shows that some Wappinger dolomite sites are already below the design minimum FN of 32. The 90 percent line intersects the FN 32 design minimum line at

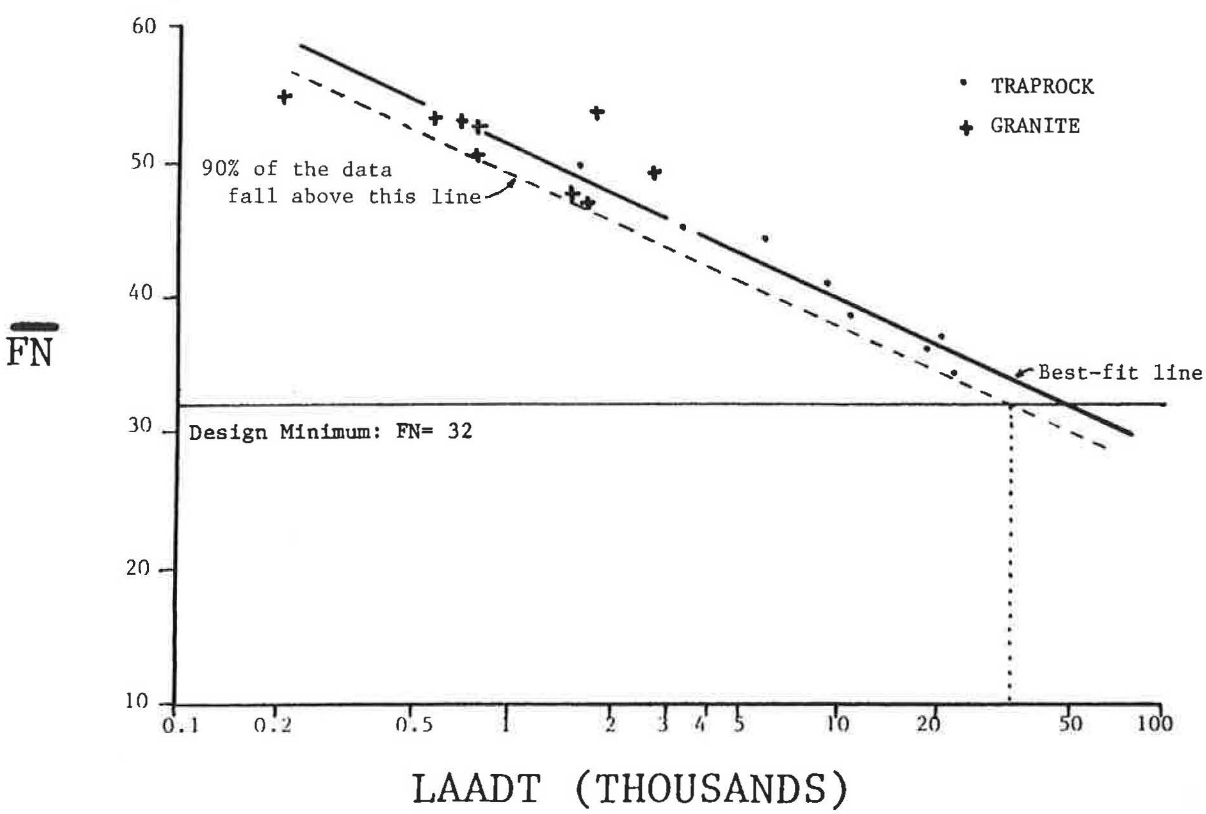

FIGURE 3 Average FN at 64 kph (40 mph) versus LAADT for sites containing traprock or granite. The 90 percent line intersects the FN 32 design minimum line at an LAADT of 33,000.

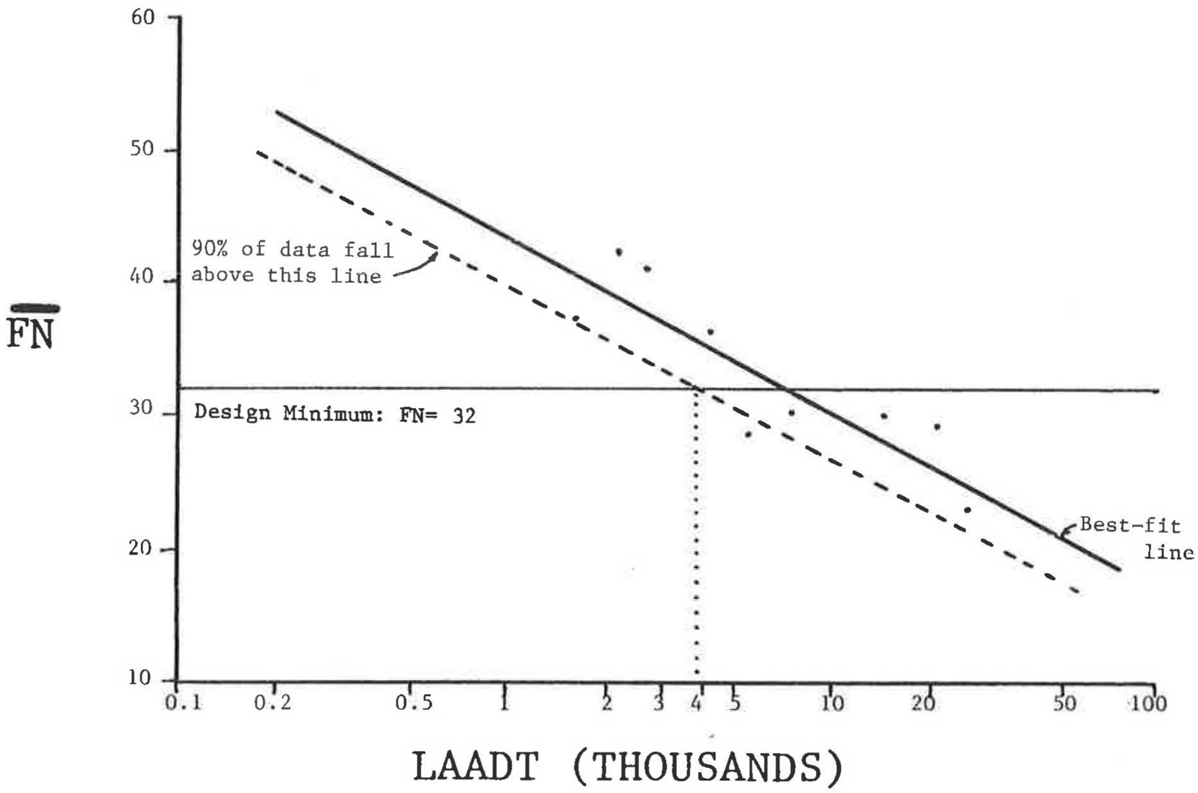

FIGURE 4 Average FN at 64 kph (40 mph) versus LAADT for sites containing Wappinger dolomite. The 90 percent line intersects the FN 32 design minimum line at an LAADT of 4,000.

an LAADT of 4,000, indicating that the Wappinger dolomite can be expected to provide adequate friction only in pavement lanes carrying 4,000 or fewer vehicles daily.

Sandy Rock Types

These rock types all contain significant amounts of sand-sized (+74 micron) quartz grains and include sandstone, siltstone, quartzite, siliceous limestone (all those tested contained more than 20 percent quartz sand), and siliceous dolomite (defined for this study as containing 15 percent or more quartz sand). Dolomites having AIRs of 15 percent or more consistently produce FNs above 40, even at high LAADTs, whereas dolomites having AIRs of less than 15 percent produce lower FNs as LAADTs increase [e.g., Wappinger dolomite (Figure 4)]. In a bituminous pavement surface, sandy rock types show a pattern of wear resulting in a continuing renewal of microtexture. As aggregate particles abrade, sand grains are displaced from particle surfaces, exposing fresh grains. Figure 5 shows a plot of sandstone sites, including sandstone, siltstone, and quartzite. These three rock types are related, differing from one another in grain size (fine versus coarse) or in degree of induration (how well grains within each particle are bonded). Although it is known from comparison of driving and passing lanes that sandstones respond to differences in traffic volume (Table 2), not enough data are available over a wide enough range of LAADTs to determine a clear trend. The renewable nature of the sandstone particle surface suggests that there may be a friction level below which a sandstone aggregate will not fall, regardless of traffic volume. Figure 5 shows that 90 percent of the sandstone data fall above an average FN of 50.

Figure 6 shows an array of data for siliceous limestones and siliceous dolomites similar to that of the sandstones, but expanded vertically. AIRs of these siliceous carbonates vary from 15 to more than 50 percent. This variable helps account for some of the data scatter, since higher AIRs tend to produce higher friction numbers (*1*). The data show, however, that these siliceous carbonate rocks can be expected to produce average FNs above 40 over a wide range of traffic volumes.

Aggregate Blends

This category includes not only combinations created in a bituminous mix plant but also naturally occurring blends, such as gravel and cherty limestone in which chert (a form of quartz) occurs in distinct nodules within a limestone matrix. Differential wearing characteristics of these blends cause friction to develop in a manner unlike homogeneous or sandy rock types. As pavements containing blended aggregate wear, softer rock types such as limestone and dolomite (having Moh's hardnesses of 3 to 4) abrade and become less prominent than harder, more resistant noncarbonate rocks such as granite and sandstone (having Moh's hardnesses of 6 to 7). This differential wearing creates a macrotexture that, in combination with the microtexture of noncarbonate rock particles, pro-

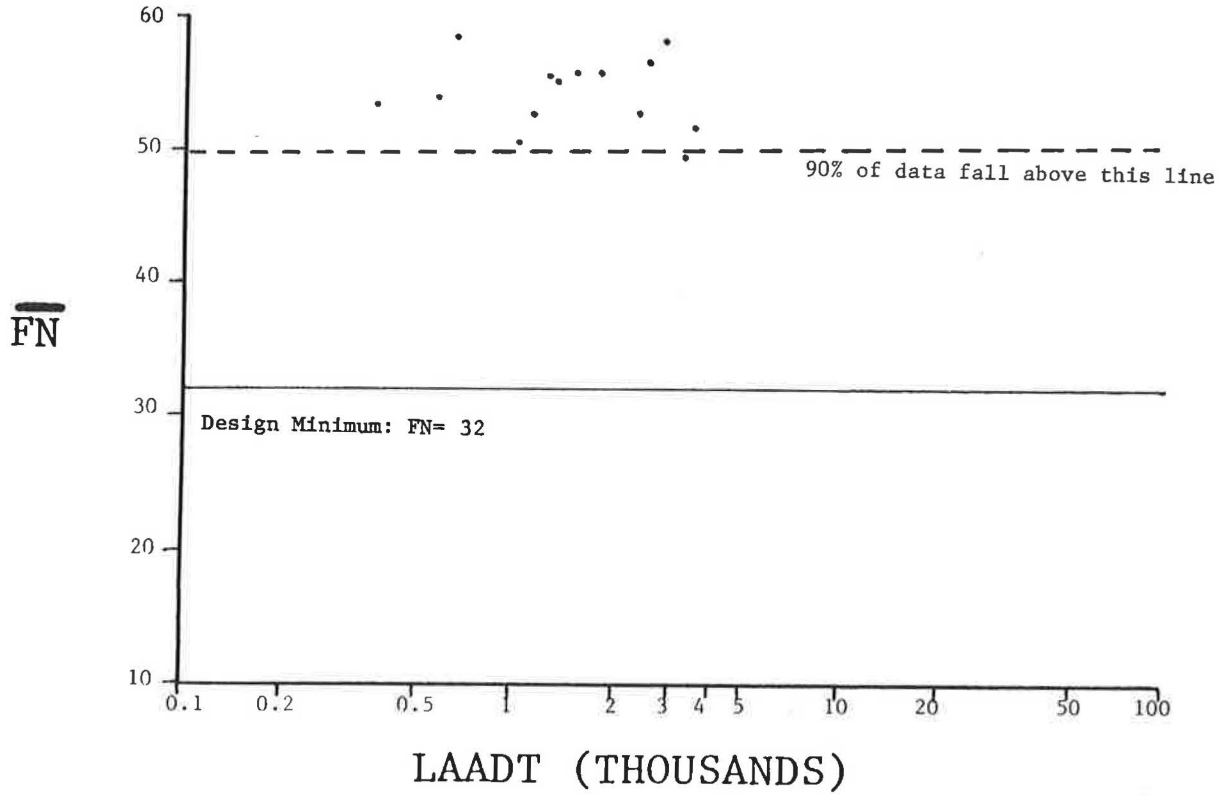

FIGURE 5 Average FN at 64 kph (40 mph) versus LAADT for sites containing sandstone.

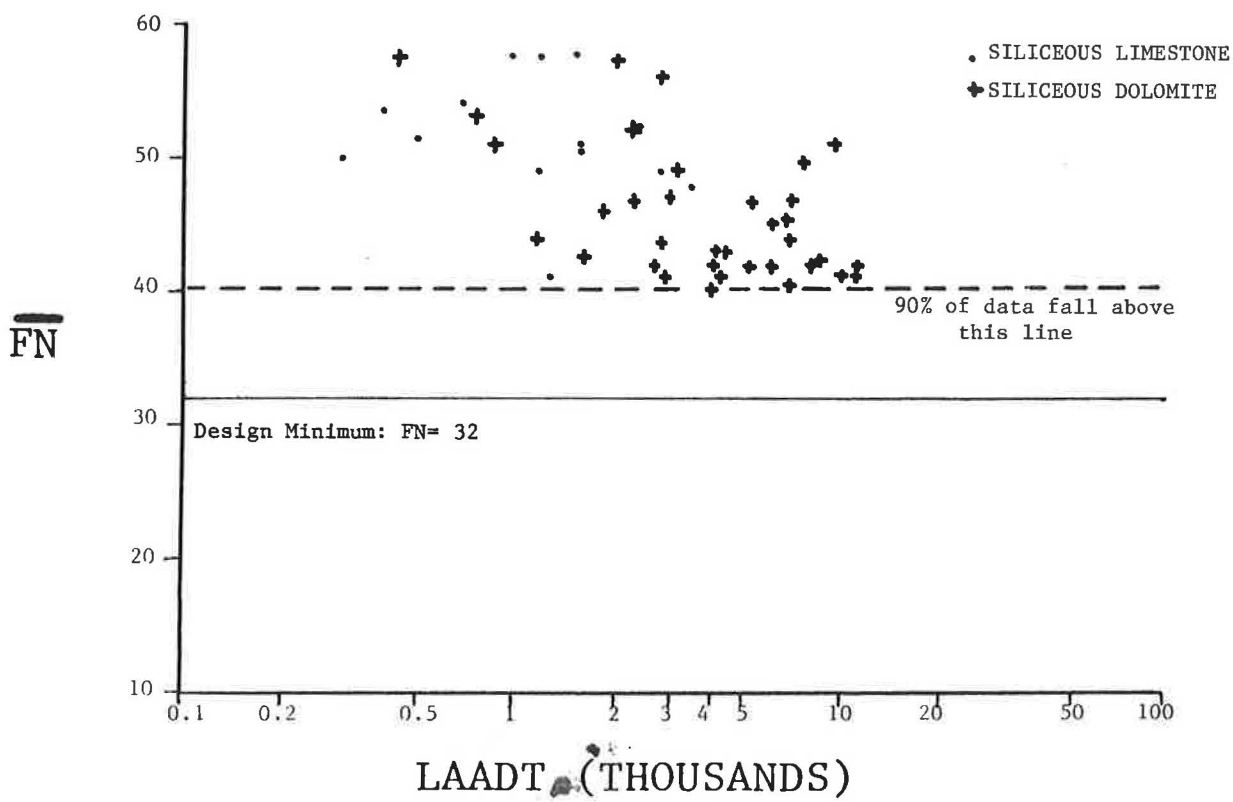

FIGURE 6 Average FN at 64 kph (40 mph) versus LAADT for sites containing siliceous limestone or siliceous dolomite.

vides the desired friction. A minimum level of noncarbonate in blends, perhaps the 20 percent required by the HFA specification, must be achieved throughout the range of LAADTs to be encountered. Two sites independent of the PFI given in Table 2 have blended aggregates containing less than 20 percent noncarbonate particles. Comparisons of driving and passing lanes show FNs both above and below the design minimum FN of 32. These blends are unacceptable both from the standpoint of the HFA specification and their measured friction. Figure 7 shows a plot of sites with blended aggregates. Data scatter can be largely accounted for by the fact that the percentage of noncarbonate particles varies from 18 to more than 70 percent. Friction tends to increase as the amount of noncarbonate in the blend increases (*7*). In spite of the scatter, the best-fit line shows the data having a negative slope. Only 5 percent of the data points fall below the FN 32 design minimum line, indicating that within the range of traffic volumes encountered in areas of the state where blended aggregates are used, the 20 percent noncarbonate requirement is generally adequate. When friction is plotted against percent noncarbonate, the data scatter is comparable with that in Figure 7. These plots show that both traffic volume and noncarbonate percentage are important and that neither can be overlooked.

NYSDOT HIGH-FRICTION AGGREGATE SPECIFICATIONS

Current NYSDOT high-friction aggregate specifications were revised in 1992 on the basis of this study:

HIGH-FRICTION AGGREGATE SPECIFICATION FOR STANDARD BITUMINOUS MIXES

Coarse aggregates shall meet one of the following high-friction requirements:

1. Coarse aggregates shall be crushed limestone that has an acid insoluble residue content of not less than 20%, excluding particles of chert and similar siliceous rocks unless approved by the Director, Materials Bureau, or crushed dolomite.
2. Coarse aggregates shall be crushed sandstone, granite, chert, traprock, ore tailings, slag, or other similar materials.
3. Coarse aggregates shall be crushed gravel or blends of two or more of the following types of materials: crushed gravel, limestone, dolomite, sandstone, granite, chert, traprock, ore tailings, slag, or other similar materials. These aggregates shall meet the following requirements:

For Type 6F Mixes—Not less than 20% (by weight with adjustments to equivalent volumes for materials of different specific gravities) of the total coarse aggregate particles (plus 1/8 inch material) shall be noncarbonate. Noncarbonate particles are defined as those having an acid insoluble residue content not less than 80%. In addition, not less than 20% of the plus 1/4 inch particles shall be noncarbonate.

For Types 7F and 8F Mixes—Not less than 20% (by weight with adjustments to equivalent volumes for materials of different specific gravities) of the total coarse aggregate particles (plus 1/8 inch material) shall be noncarbonate.

HIGH-FRICTION AGGREGATE SPECIFICATION FOR HEAVY-DUTY AND RUT-AVOIDANCE BITUMINOUS MIXES

(These mixes will be used on pavements having LAADTs over 4000 daily vehicle passes)

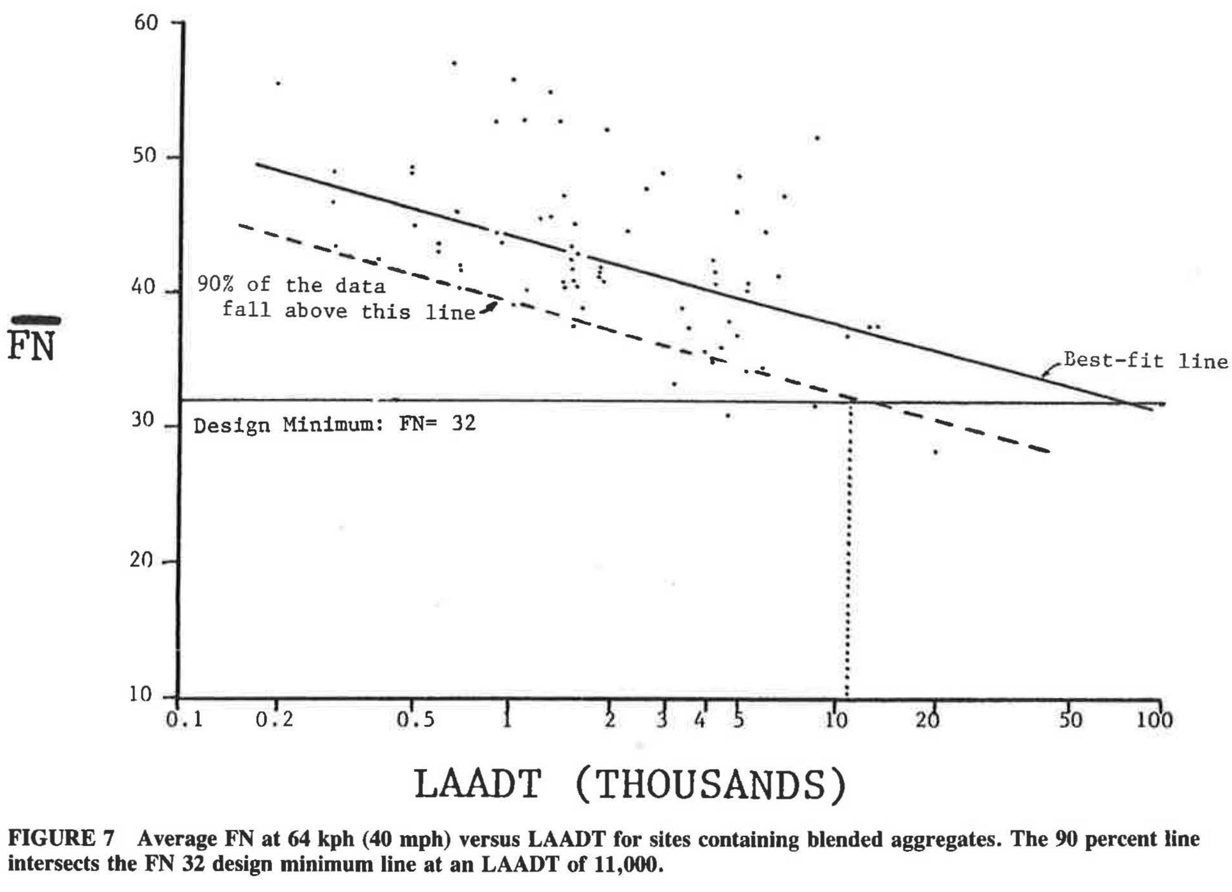

FIGURE 7 Average FN at 64 kph (40 mph) versus LAADT for sites containing blended aggregates. The 90 percent line intersects the FN 32 design minimum line at an LAADT of 11,000.

Coarse aggregates shall meet one of the following high-friction requirements:

1. Coarse aggregates shall be crushed limestone that has an acid insoluble residue content of not less than 20%, excluding particles of chert and similar siliceous rocks unless approved by the Director, Materials Bureau.
2. Coarse aggregates shall be crushed sandstone, granite, chert, traprock, dolomite (excluding Wappinger Dolomite), ore tailings, slag, or other similar materials.
3. Coarse aggregates shall be crushed gravel or blends of two or more of the following types of materials: crushed gravel, limestone, dolomite (including the Wappinger Dolomite), sandstone, granite, chert, traprock, ore tailings, slag, or other similar materials. These aggregates shall meet the following requirements:

   For Types 6FHD and 6FRA Mixes—Not less than 20% (by weight with adjustments to equivalent volumes for materials of different specific gravities) of the total coarse aggregate particles (plus 1/8 inch material) shall be noncarbonate. Noncarbonate particles are defined as those having an acid insoluble residue content not less than 80%. In addition, not less than 20% of the plus 1/4 inch particles shall be noncarbonate.

   For Type 7FHD and 7FRA Mixes—Not less than 20% (by weight with adjustments to equivalent volumes for materials of different specific gravities) of the total coarse aggregate particles (plus 1/8 inch material) shall be noncarbonate.

CONCLUSIONS

On the basis of an analysis of friction data from 155 pavement sites in the NYSDOT PFI program and from an additional 66 sites previously tested by the department, the following conclusions are drawn:

1. Bituminous pavements reach a terminal polish state within 2 to 3 years, after which the coefficient of friction can be expressed as an average of all measurements. This conclusion was largely inferred from the PFI data and bolstered by data from an independent site (Figure 2).

2. Pavement friction is inversely related to daily traffic volume, expressed as LAADT. Data from homogeneous rock types demonstrate this relationship best, but comparisons of driving and passing lanes show that it also holds true for both sand and blended aggregates (Table 2).

3. Aggregate rock types can be categorized as homogeneous, sandy, or blended, and on the basis of this classification an aggregate's wearing and polishing characteristics can be predicted.

4. Traprocks, granites, sandstones, siliceous carbonates (as defined for this study), and aggregate blends containing 20 percent or more noncarbonate particles can be expected to provide adequate friction throughout the range of traffic volumes normally encountered (traprocks and granites, LAADTs up to 30,000; sandstones and siliceous carbonates, no upper limit on LAADT; aggregate blends, LAADTs up to 10,000).

5. Wappinger dolomite, with an AIR below 15 percent, can be expected to provide adequate friction only in pavements with LAADTs under 4,000. NYSDOT has restricted the use of Wappinger dolomite in pavements having LAADTs of 4,000 or more.

ACKNOWLEDGMENTS

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