DEVELOPMENT OF SPECIFICATIONS FOR SKID-RESISTANT ASPHALT CONCRETE

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This paper summarizes 10 years of research in New York State on the skid resistance of asphalt pavements. Skid numbers measured by a two-wheeled trailer are related to cumulative vehicle passes for the state's geologic formations that are sources of coarse aggregate for asphalt concrete. Mixes with coarse aggregate containing at least 20 percent noncarbonate stone—or 10 percent sand-sized impurities embedded in a carbonate matrix—remain skid resistant for the life of the pavement. Specifications have been written to require aggregates not meeting these requirements to be upgraded by blending them with 20 percent noncarbonate stone.

• FROM 1961 through 1966, the death toll on U. S. highways increased annually by an average of 6.9 percent, from 38,093 to 53,041 persons. The National Safety Council (1) estimated that 1966 motor vehicle accidents cost the country more than $10 billion in lost wages, medical and hospital fees, insurance administrative and claims settlement costs, and property damage.

Such statistics prompted the Congress to pass the Highway Safety Act of 1966. As a result, on June 27, 1967, the Highway Safety Bureau of the U. S. Department of Transportation issued 13 highway safety program standards that were "designed to reduce traffic accidents and deaths, injuries, and property damage resulting therefrom." One of these standards (No. 4.4.12) required that every state "have a program of highway design, construction, and maintenance to improve highway safety."

Because as many as 33 percent of all wet-weather accidents involved or were caused by skidding (2, 3), two of the 11 minimum requirements of this standard call for every state to have "standards for pavement design and construction with specific provisions for high skid resistance qualities," and "a program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets or highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces."

To fulfill the second requirement, the engineering research and development bureau of the New York State Department of Transportation completed a statewide inventory of the skid resistance of the entire state highway system in 1968 and 1969. During this survey, the skid number (wet 40-mph coefficient of friction × 100) was measured once per mile on nearly all the 14,000 miles of state highways, and the locations of most pavement sections with low skid resistance were determined.

Before conducting the statewide skid survey, the bureau had an ongoing research program to determine which pavement variables affected the skid resistance of asphalt concrete plant mixes. Previously reported New York research (4) had shown this skid resistance to be governed by the following factors:

1. Cumulative traffic the pavement had carried,
2. Vehicle speed,
3. Pavement and tire temperatures, and
4. Polishing resistance of the larger mix aggregates.

Sponsored by Committee on Surface Properties-Vehicle Interaction.

Skid resistance was not significantly influenced by mix type (for mixes containing 15 to 70 percent aggregate greater than $1/8$ in.) or by the type of fine (less than $1/8$ in.) aggregate. (Natural silica sand and manufactured carbonate fines performed nearly the same as similar coarse aggregate.)

New York State specifications require the use of crushed-stone coarse aggregate (greater than $1/8$ in.) in asphalt concrete, but the aggregate particle shape and its orientation in the pavement surface caused variations in the time required to wear the asphalt coating off the individual stones, and thus large variations in skid resistance were observed during the first million vehicle passes on asphalt concrete pavements. After the asphalt had worn off, additional traffic caused a logarithmic decrease in skid resistance due to aggregate polishing.

Previous research (4) showed a correlation between pavement skid resistance and the percentage of acid-insoluble material in the coarse aggregate of asphalt concrete pavements that had carried over 5 million vehicles. The amount of acid-insoluble residue was determined by the method described in the Appendix. In all cases, limestone and dolomite aggregates with less than 10 percent acid-insoluble residue produced pavements with inadequate skid resistance. A pavement was considered skid resistant if it maintained a skid number (wet at 40 mph) of 32 or more for 10 million vehicle passes. This number was selected as a guide because it corresponded to the skid resistance assumed by AASHO for calculating stopping distances used in highway design (5). At skid numbers above 32, a normal driver will be able to perceive an object in his path, apply his brakes, and stop his vehicle before striking that object. Because many New York State stone suppliers produce aggregates with less than 10 percent acid-insoluble residue, further research was initiated to determine the most practical and economical way to upgrade these aggregates so as to produce skid-resistant asphalt concrete pavements.

TEST PROCEDURE AND RESULTS

Procedure

In all skid testing, the New York State two-wheeled drag force trailer was used in a procedure conforming to ASTM Designation E 274-70. A standard test tire (ASTM Designation E 249-66) was used. Tests were usually made on level, tangent road sections because of the uncertainty in weight transfer onto or off the test wheel when traversing a curve. This weight transfer changed the magnitude of load carried by the test tire, from which the coefficient of friction was computed. Previous reports (4, 6) documented the reliability of the skid-trailer measuring system and its ability to correlate with the distance required to stop a car traveling at 40 mph.

During the 10 years of research, many thousands of skid tests have been performed on pavements containing aggregates from nearly every crushed-stone source that supplies asphalt concrete producers in New York State. In addition, over 10,000 asphalt pavements were tested during the 1968 and 1969 skid inventory of the state highway system. With the assistance of the department's highway maintenance subdivision and regional materials engineers, coarse aggregate sources were determined for almost all asphalt concrete pavements that had been skid tested. Surface course age was also checked, and the cumulative vehicle passes were calculated. Acid-insoluble residue tests were conducted on all geologic formations that were sources of coarse aggregate for asphalt concrete in New York. Carbonate staining tests were conducted on all Onondaga limestones. The methods used for both of these tests are given in the Appendix.

In addition, 51 experimental surfaces were placed on state highways in three regions. These contained varying quantities of hard acid-insoluble materials, and the mix types ranged from fine sheet asphalts to dense-graded asphalt concrete with up to 30 percent aggregate of $1/4$ to $1/2$ in. size.

Results

To relate pavement skid number to coarse aggregate geologic formations we conducted detailed analyses on all available skid test data on asphalt concrete pavements.

Figure 1 shows skid number as a function of cumulative traffic (on a log scale) in millions of vehicles per lane for pavements containing limestone coarse aggregate from the Manlius, Coeymans, Tully, and Cobourg formations and the Chazy and Black River groups from quarries located in central and north central New York. Limestones from these six geologic formations are high in calcium carbonate and contain only minor quantities of hard sand-sized impurities (less than 10 percent acid-insoluble residue). The figure shows the best-fit line and the 80 percent confidence lines. After 10 million vehicle passes, only 10 percent of the roads containing these coarse aggregates would be expected to be skid resistant, i.e., to have skid numbers above 32. The two confidence lines in Figure 1A are used as reference lines in Figure 1B and the other three figures. Also, each point on these graphs represents an average of seven or eight skid tests on one pavement section.

Figure 1B shows a similar plot for skid data representative of the Oak Orchard member of the Lockport dolomite formation, in the western part of the state. The Oak Orchard dolomite is high in carbonates (over 90 percent) and low in quartz (less than 2 percent). While the data are very few, the skid numbers are in the same range as the high-carbonate limestones in Figure 1A.

Figure 2 shows a comparison of the high-impurity dolomites with the relatively pure limestones of Figure 1A. These dolomites include the Penfield, Goat Island, and Gasport members of the Lockport formation and a special unit of the Lockport identified as the Brockport Lentil. Also included are the Beckmantown, Cranesville, and Little Falls formations. The Penfield member and the Brockport Lentil are characterized by high silica contents. In the Goat Island and Gasport members, the silica content varies both laterally and vertically. In general, however, the percentage of silica is slightly higher in the Goat Island and Gasport members than in the Oak Orchard member (Fig. 1B) but considerably less than in the Penfield one. The Beckmantown, Cranesville, and Little Falls formations have noncarbonate contents exceeding 15 percent. These dolomites, all containing more than 10 percent hard sand-sized impurities, have higher skid resistance than the low-impurity limestones or dolomites. About 10 percent of the pavements containing these dolomites had skid numbers in the unacceptable range of the low-impurity limestones.

One of the most extensive sources of coarse aggregate in New York State is the Onondaga limestone formation, which occurs in an east-west band from the vicinity of Albany to Buffalo. The Onondaga formation contains chert (a flint-like quartz) nodules in varying quantities: a relatively low percentage at Syracuse but increasing to 40 percent or more westward near Buffalo. The chert does not appear in the softer limestone matrix but rather in a variety of forms ranging from whole pieces of crushed aggregate to a small chip on the edge of a piece of limestone aggregate. The percentage of chert was determined by the staining procedure rather than by the acid-insoluble residue test.

Figure 3 shows a plot of skid numbers versus traffic for 93 pavements in which the coarse aggregate was Onondaga limestone. The extreme ranges of skid resistance on these pavements were attributable to the varying percentages of chert particles in the coarse aggregate. The pavements with skid numbers in the same range as the pure limestones contained aggregates with less than 15 percent chert (open circles), whereas those with higher skid numbers (solid circles) ranged from 20 to 50 percent chert.

Sandstone, granite, and traprock (diabase) are grouped for this analysis because they are all noncarbonates. All sandstones are of the Graywacke type in either the Catskill or Rensselaer formations and are quarried in the southern and eastern part of the state. The granites are quarried mostly in the Adirondack Mountains in northern New York, but one granite quarry is located just north of New York City. Traprock occurs in the lower Hudson River Valley and is also imported from New Jersey and Connecticut. The acid-insoluble residues for these aggregates ranged from 93.0 to 99.6 percent. Figure 4 shows the skid resistance of noncarbonates and pure limestones at various traffic volumes. The noncarbonates are clearly superior, even after 10 million vehicle passes.

Figure 1. Skid resistance change with traffic for pavements containing coarse aggregates with low acid-insoluble contents (A—91 pavements; B—6 pavements).

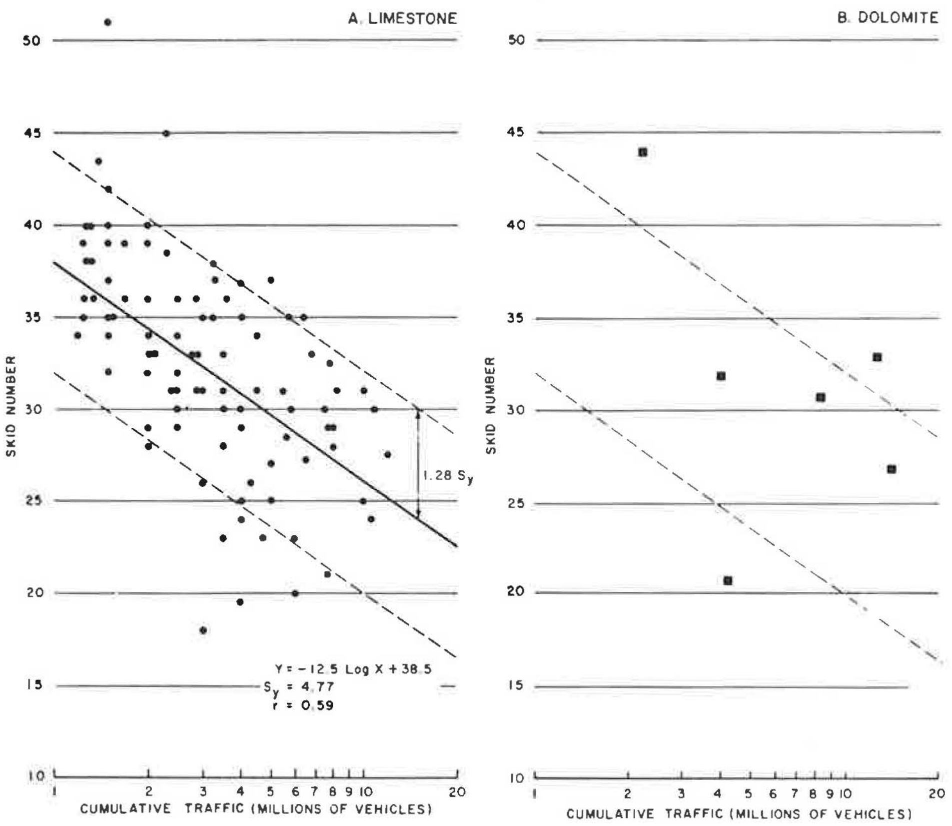

Figure 2. Skid resistance change with traffic for pavements containing low-impurity limestones and dolomites having more than 10 percent acid-insoluble residue (169 pavements).

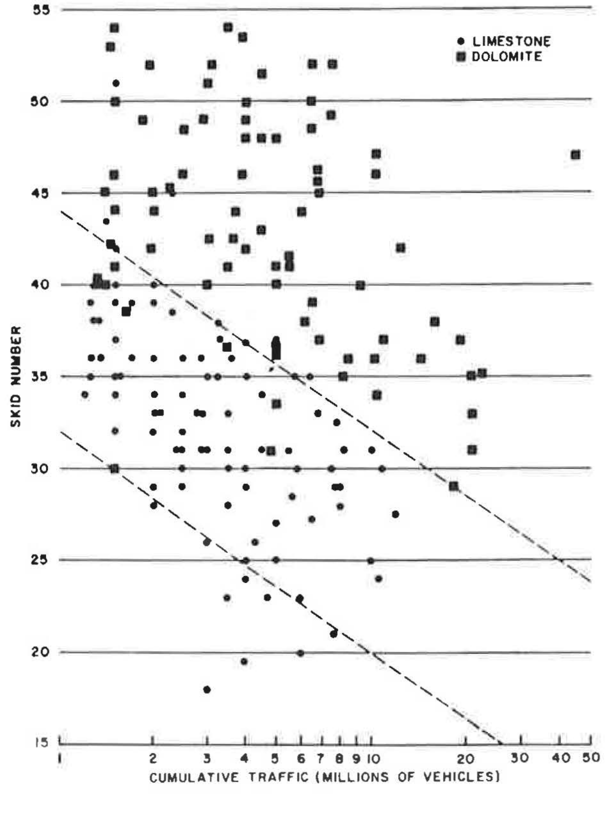

Figure 3. Skid resistance change with traffic for pavements containing limestones varying in percentage of noncarbonate material (93 pavements).

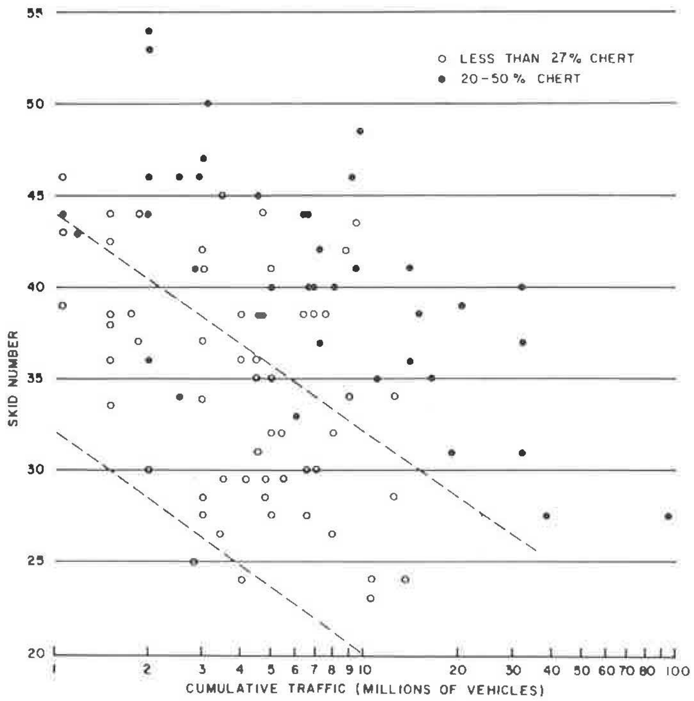

Figure 4. Skid resistance change with traffic for pavements containing low-impurity limestones and noncarbonates (117 pavements).

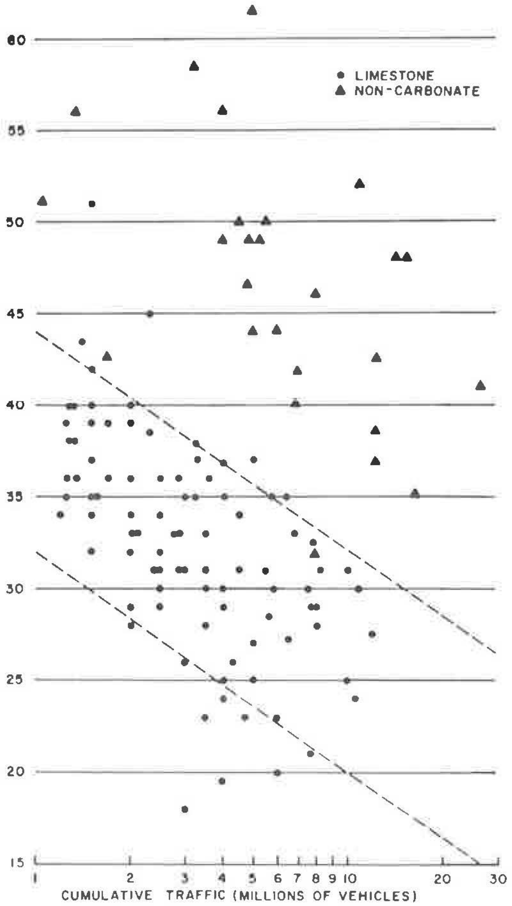

Table 1. New York State coarse aggregate suppliers.

Item	No. of Suppliers	Total
Quarried material		
Limestone	38	
Dolomite	24	
Sandstone, traprock, and granite	27	89
Geologic formations		22
Operating asphalt mix plants		182

Table 2. Mix proportions in New York State Types 1A and 1AC asphalt concrete plant mixes.

Material	Type 1A (percent)	Type 1AC (percent)
+$^1/_4$ in. stone	20	—
+$^1/_8$ in. stone	35	45
-$^1/_8$ in. fines	45	55
Asphalt cement	6.5	7

IMPLEMENTATION OF RESULTS

Analyzing the long-term skid resistance of asphalt concrete mixes as related to the mineralogy of the coarse aggregate has permitted the following classification of aggregate:

1. Carbonates with less than 10 percent sand-sized impurities,
2. Mixtures of carbonate and noncarbonate aggregates with less than 20 percent noncarbonates,
3. Carbonates with more than 10 percent impurities,
4. Mixtures (carbonates and noncarbonates) with more than 20 percent noncarbonates, and
5. Noncarbonates, defined as any aggregate with more than 80 percent acid-insoluble residue.

Aggregates in the first two categories have been judged incapable of providing long-term skid resistance (up to 10 million vehicle passes) in asphalt mixes. Aggregates in any of the other categories will produce pavements generally resisting polishing throughout their lives.

A breakdown of coarse aggregate suppliers by type of stone being quarried is given in Table 1. At present, two-thirds of the total 89 quarries produce carbonate rock (limestone and dolomite). It is readily apparent that any specifications affecting the suitability of carbonate rock aggregate in New York could have serious consequences in increased costs of asphalt concrete and shortages of acceptable coarse aggregate. Consequently, care was necessary to ensure that the department did not make requirements more stringent than necessary for adequate long-term skid resistance.

After a thorough analysis of research data and due consideration for the aggregate resources available in New York State, the following specification was prepared to ensure long-term skid resistance of asphalt pavements. It applies only to the coarse aggregates used in surface course mixes placed on roads where the anticipated cumulative traffic per lane during the design life of the pavement surface exceeds 1 million. All other department specifications governing the mixing plant, materials, and construction details must still be followed. The specification was written to cover Types 1A and 1AC asphalt plant mixes, which are the most frequently used surface courses in New York. Typical mix proportions are given in Table 2.

The new specification requires that coarse aggregates be from approved sources and that they meet one of the following requirements:

1. They may be limestone from the Onondaga formation, but must contain at least 20 percent chert particles;
2. They may be either from a dolomite formation or from a limestone formation other than Onondaga, but they must contain at least 10 percent sand-sized acid-insoluble impurities; or
3. They may be noncarbonate crushed stone such as sandstone, granite, traprock, slag, or similar materials.

Aggregates not meeting any of these requirements naturally must be upgraded by blending them with noncarbonates and are covered under the following requirement:

4. The coarse aggregate may be a blend of carbonates (limestone or dolomites) and noncarbonates (sandstone, granite, traprock, slag, etc.) provided (a) that 20 percent of all stone over $1/8$ in. is noncarbonate and (b) that, if stone over $1/4$ in. is included, 20 percent of it is also noncarbonate.

The producer has the option to upgrade with noncarbonate stone from $1/4$ to $1/2$ in. in a Type 1A mix, but in the final mix the total aggregate over $1/8$ in. must have at least 20 percent noncarbonate particles. When the aggregates are from more than one source, or of more than one type of material, they must be proportioned and blended to provide a uniform mixture. If lightweight aggregate or slag is used as the noncarbonate, the requirement of 20 percent by weight must be adjusted for the different specific gravities.

Because this specification has been in force only two complete construction seasons, long-term effects on skid resistance cannot yet be evaluated. During these 2 years, 29 pavements containing blended aggregates have been sampled and will serve as test sections to determine whether additional specification changes are needed. Some dolomite sources that just meet part of this specification are being monitored to see whether the 10 percent acid-insoluble impurity requirement can or should be modified.

ACKNOWLEDGMENTS

The research project reported here was initiated by and progressed for the first 5 years after its approval with the support of the Federal Highway Administration under the supervision of John L. Gibson, senior civil engineer, now assigned to the staff of this department's Region 1. Under his direction and that of the senior author, the following technicians were responsible for field skid testing: Anthony J. Datri, Ronald Lorini, Raymond J. Mazuryk, David J. Rothaupt, James H. Tanski, and Thomas F. VanBramer. The resulting data were reduced and plotted by Nancy B. Couture.

Geological information was furnished by George D. Toung, assisted by Paul J. St. John and Edward A. McGrady, each from the materials bureau. The following regional materials engineers assisted in determining the aggregate sources for numerous pavements tested and in selecting sites for the experimental pavement sections: Frank A. DeFazio and John J. Pinto, Region 2; John P. Russell and Lawrence A. Colelli, Region 3; Alfred R. D'Annunzio and M. Dwight Vail, Region 4; James W. Foersch, Region 5; Eugene N. Thiebeau, Region 7; Donald F. Fullam, Region 8; Charles F. Donahue, Region 9; and Leland C. Fitts and William Thornwell, Region 10.

The assistance of the technical committee of the New York State Crushed Stone Association and the New York State Bituminous Producers Association in preparing the new specification is also gratefully acknowledged.

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APPENDIX

EXTRACTS FROM NEW YORK STATE MATERIALS TEST METHODS

A. Test for Acid-Insoluble Residue (Coarse Aggregate)

1. Scope

   Determine the resistance of aggregates to loss when exposed to a hydrochloric acid solution.

2. Test Solutions
   a. $2N$ hydrochloric acid (5 parts distilled water and 1 part $12N$ hydrochloric acid, reagent grade).
   b. $6N$ hydrochloric acid (1 part distilled water and 1 part $12N$ hydrochloric acid, reagent grade).

3. Procedure
   a. A representative sample of the aggregate is screened over $\frac{1}{2}$- and $\frac{1}{8}$-in. sieves. The aggregate retained on the $\frac{1}{8}$-in. sieve is reduced to a test sample having a minimum size of 300 particles and weighing a minimum of 50 grams, after excluding any chert or other similar siliceous rock particles.

   b. The sample is thoroughly cleaned by washing with potable tap water and dried to a constant weight in an oven at 221 to 230 F (105 to 110 C). Then the clean sample is weighed to the nearest 0.1 gram and placed in the glass container.
   c. The aggregate sample is subjected to a 2 *N* hydrochloric acid solution until the chemical reaction ceases. Temperatures of the aggregate and the acid should be between 70 and 80 F at the beginning of test. Decant and repeat the addition of fresh 2 *N* acid. Repeat this step of decanting the spent acid and adding fresh acid until there is no further reaction.
   d. When reaction with the 2 *N* hydrochloric acid stops, repeat the same procedure using 6*N* hydrochloric acid. When all reaction stops, the acid solubility test is complete.
   e. Decant the acid solution and rinse the aggregate thoroughly with water in the glass container. The residue in the container should have a pH (as indicated by pH paper) of more than 5.5 after washing.
   f. Carefully transfer the residue from the container to a No. 200 sieve and wash thoroughly.
   g. Dry the acid-insoluble residue to a constant weight in an oven at 221 to 230 F (105 to 110 C) to determine the percentage insoluble.

4. Calculations

$$\text{Percent insoluble residue} = \frac{\text{Weight retained on the No. 200 sieve}}{\text{Weight of the original test sample}}$$

B. Test for Percentage of Noncarbonate Particles in a Coarse Aggregate Mixture (Carbonate Staining Method)

1. Scope
   Determine the percentage of noncarbonate rock in a coarse aggregate mixture by a staining technique, to separate the carbonate particles from the noncarbonates.
2. Definition of Terms
   A carbonate particle is defined as one with 60 percent or more of its surface area stained after test, and a noncarbonate particle as one having less than 60 percent stained.
3. Test Solutions
   a. Copper nitrate (molar solution), 1 liter of the molar solution being prepared by adding the indicated amounts of one of the following nitrates to 1,000 grams of distilled water: 188 grams of $Cu(NO_3)_2$; 225 grams of $Cu(NO_3)_2 \cdot 3H_2O$; or 332 grams of $Cu(NO_3)_2 \cdot 6H_2O$.
   b. Ammonium hydroxide (concentrated commercial grade), NH_4OH_3.
4. Procedure
   a. A representative sample of the aggregate must meet the following size requirements:

Size	Minimum No. of Particles	Minimum Weight (gram)
+¼ in.	200	300
+⅛ in.	300	50

   b. The retained sample of aggregate is thoroughly washed with potable tap water, and dried to a constant weight in an oven at 221 to 230 F (105 to 110 C).
   c. The sample is weighed to the nearest 0.1 gram and placed in a glass or polyethylene container.
   d. The aggregate is completely covered with the copper nitrate solution for a minimum of 4 hours.
   e. Decant the copper nitrate solution, and immediately add the concentrated ammonium hydroxide. Allow the sample to remain immersed for at least 1 min.
   f. Decant the ammonium hydroxide, and carefully wash the sample with potable tap water.
   g. Limestone is stained blue or bluish-green. Dolomite is only slightly affected. Separate all stained limestone (carbonate) particles and all dolomite particles (by visual examination by a geologist) as defined under item 2.
   h. Dry the noncarbonate portion of the sample to a constant weight in an oven at 221 to 230 F (105 to 110 C) to determine the percentage of noncarbonate particles.
5. Calculations
   Compute the noncarbonate percentage as follows:

$$\text{Percentage of noncarbonate} = \frac{W_{ncp} \times F \times 100}{W_o}$$

where

W_{ncp} = weight of oven-dry noncarbonate particles,
W_o = weight of oven-dry original test sample, and
F = adjustment factor for differing specific gravities of noncarbonate rocks.

Select the proper F-value in the following table:

Noncarbonate Material	Specific Gravity	F-Value[a]
Iron ore tailings	3.10	0.871
Traprock	2.90	0.931
Chert	2.70	1.000
Granite	2.70	1.000
Sandstone	2.67	1.011
Blast furnace slag	2.45	1.102
Sinopal	2.18	1.239
Lightweight aggregates	1.60	1.688

[a] *The F-value may be used with carbonate particles having a specific gravity range of 2.67 to 2.73. For any carbonate rock having a specific gravity outside this range, the F-value must be computed using the following equation:*

$$F = \frac{\text{Carbonate specific gravity}}{\text{Noncarbonate specific gravity}}$$