Effect of Slag Type on Tufa Precipitate Formation

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Tufa, a precipitated form of calcium carbonate, has been observed occluding underdrain outlets, catch basins, and storm sewers in various counties in east and northeast Ohio. Previous research determined that slag used as a subbase was the only factor directly related to the formation of tufa precipitate. However, no differentiation was made among the various slag types used. This study was initiated to determine whether different types of slag affected the formation of tufa precipitate. A total of 37 projects with different types of slag subbase were inspected. Subbases composed of blast furnace slags or steam boiler slag did not promote formation of tufa precipitate. However, because of the presence of free lime in steel slags and slacker aggregate, subbases composed of these materials did promote the formation of tufa precipitate (open hearth slag to a lesser extent than the other types). Long-term stockpile aging of open hearth slag appeared to reduce the amount of free lime sufficiently to lessen the volume of tufa precipitate to acceptable levels.

Tufa, a precipitated form of calcium carbonate, has been observed occluding underdrain outlets, catch basins, and storm sewers in various counties in eastern and northeastern Ohio, as shown in Figure 1. Examples of this condition are shown in Figures 2 and 3. The blockage of the highway drainage system impedes proper drainage of the highway pavement subbase and subgrade, resulting in accelerated deterioration of pavement such as that observed in Figures 4 and 5. The section of freeway has a low volume of truck traffic, yet severe deterioration has occurred.

Feldman (*1*) found that the use of slag as subbase was the only factor directly related to the formation of tufa deposits observed in Ohio. Although precipitate formations have been linked to the use of recycled portland cement concrete for subbases in other states, Ohio has yet to use this particular material as a subbase. Free lime (calcium oxide) in the slag subbase dissolves as water from the roadway surface percolates through the subbase to the subsurface drainage system. This reaction can be expressed by the following chemical equations:

$$CaO + H_2O \rightleftharpoons Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 \rightleftharpoons Ca^{++} + 2(OH)^- \quad (2)$$

The resulting calcium hydroxide solution produces drain waters with pH values consistently above 11.0. The high pH of the drain waters creates an environment in which the weak carbonic acid, H_2CO_3, formed by the air and water in the underdrain pipes and storm sewers, disassociates into hydrogen and carbonate ions. This reaction can be expressed by the chemical equations:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \quad (3)$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \quad (4)$$

$$H\,CO_3^- \rightleftharpoons H^+ + CO_3^= \quad (5)$$

In a high pH environment Equations 4 and 5 will be favored to go from left to right.

The carbonate ions in solution combine with the calcium ions to form calcium carbonate. This reaction is expressed by the chemical equation:

$$Ca^{++} + CO_3^= \rightleftharpoons CaCO_3 \quad (6)$$

In a high pH environment the equation above is favored to go from left to right, resulting in formation of tufa precipitate in the underdrain and sewer systems.

Although Feldman determined that slag used as subbase material was the cause of tufa precipitate formation, no differentiation was made among the various types of slag used in highway construction. Different types of slag have significantly different compositions (*2, 3*). The various types of slag used in highway construction in Ohio are discussed briefly.

Blast furnace slag is produced as a byproduct during production of crude iron. It is formally defined as "the nonmetallic product consisting essentially of silicates and alumino-silicates of lime and other bases, which is developed in molten condition simultaneously with iron in a blast furnace." Iron ore, coke, and fluxstone (lime and other metallic oxides) are "burned" in the blast furnace at approximately 3,000°F. The fluxstone reacts with the impurities in the iron ore to form molten slag and molten crude iron. In this carefully controlled process the entire amount of lime and other fluxstone are used to remove impurities from the iron ore. This results in slag which is composed of complex silicates and alumino-silicates, and is devoid of free lime and other simple metallic oxides. Although blast furnace slag is a basic (pH greater than 7.0) material, it is relatively insoluble in plain water because of the complex nature of its constituents.

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FIGURE 1 Areas in Ohio where tufa precipitate has been observed.

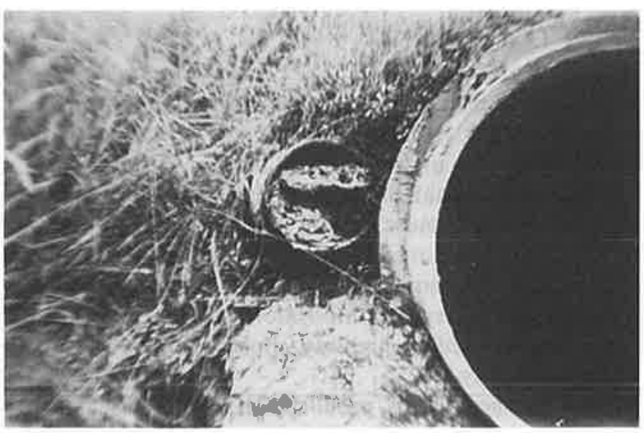

FIGURE 2 Tufa precipitate occluding underdrain outlet.

FIGURE 3 Tufa precipitate flume on fill slope.

There are two types of blast furnace slag used in highway subbases. Air-cooled blast furnace slag is allowed to solidify in mass under atmospheric conditions. After it has solidified, the slag is dug and crushed into the desired grading. Granulated slag is rapidly solidified by immersion in water to form a glossy, granular product sometimes referred to by users as popcorn.

Steel-making slags are nonmetallic byproducts formed during the refining of crude iron into steel. Practically all steel in the United States has been produced by open hearth, basic oxygen, or electric arc furnaces. Current environmental restrictions have eliminated use of the open hearth process. However, stockpiles of open hearth slag are still available.

The steel furnaces are charged with an abundance of flux material so as to remove almost all the impurities in crude iron. The resulting slags are composed of not only the complex silicates and alumino-silicates, as in blast furnace slag, but also free lime and other simple metallic

FIGURE 4 Deteriorated pavement section.

FIGURE 5 Tufa precipitate at edge of shoulder.

oxides. Figure 6 shows free lime in vesicules of steel slag. Generally, electric arc slags and basic oxygen slags have much higher concentrations of free lime, approximately 2 percent to 12 percent by weight, than open hearth slags. The specific free lime content of open hearth slags has not been measured. Steel slags are basic materials and the free lime portion is highly soluble in water.

Slacker aggregate is a byproduct of burning limestone to form the lime flux used in iron and steel furnaces. This product has a high concentration of free lime. The specific amount has not been determined, but it is equal to or greater than that of basic oxygen slag. Its use has been discontinued in the latest Ohio Department of Transportation specifications.

Steam boiler slag is actually not slag at all but an acidic bottom ash formed by burning coal to produce electric power. It is devoid of any free lime and other simple metallic oxides.

Because previous research did not distinguish the various types of slag with their different compositions, this study was undertaken to determine whether the type of slag used in subbase affected the formation of tufa precipitate. Comparing the chemistry of tufa precipitate formation to the composition of the different types of slags, it was believed that steel slags and slacker aggregate would produce tufa precipitate while the blast furnace slags and steam boiler slag would not. To confirm this hypothesis, several highway projects in which different types of slag had been used for subbase material were inspected to determine whether tufa precipitate was present.

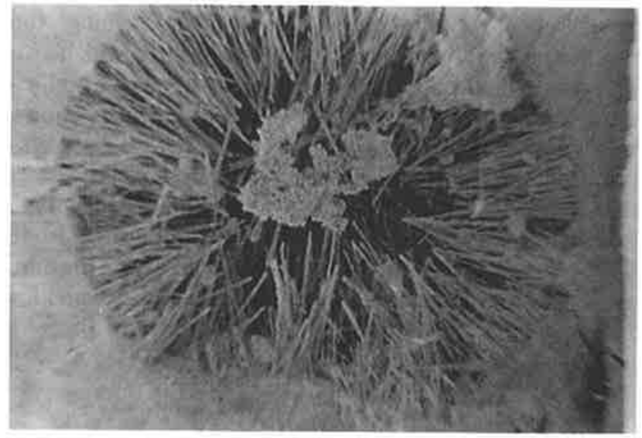

FIGURE 6 Free lime in steel slag vesicule.

SITE SELECTION

The computer records of the Ohio Department of Transportation Bureau of Tests were searched to develop a listing of all projects where slag samples had been taken for any use. Unfortunately these records dated back only to projects sold after 1968. Therefore, no specific information was available on most of the projects studied by Feldman. Information on the initial listing was limited to project number and year, slag use for each sample taken, and type of slag for each sample. The projects to be inspected were selected from the initial listing by a process of elimination.

Projects in which slag had not been used as subbase material were eliminated from the list of candidate sites. The remaining projects were looked up in bidding pamphlets listing the amount of various items used on each project. The amount of subbase on the project, the type of project, and whether underdrains had been provided were determined for each project.

Projects in which underdrains either had not been provided or provided only in small amounts were eliminated from the list of candidate sites, as were projects with very small amounts of new subbase, such as small widening and resurfacing projects. It was felt that conclusive results would be obtained only by observing projects with large quantities of slag subbase and numerous underdrain outlets.

It was intended at first to inspect only those projects where the subbase was composed entirely of one particular type of slag. As this would have severely limited the number of projects observed, some projects in which two types of slag had been used were added after some preliminary conclusions were reached from initial inspections. An attempt was made to limit the two slag-type projects to those with either both blast furnace slags or both steel slags. When this was not possible, additional two-slag type projects were selected which had a predominance of one type of slag. When information was available, slag producers' records were checked to verify the slag types listed for the projects. Types of slags and the number of projects using those slag types are summarized in Table 1.

TABLE 1 SUMMARY OF SLAG TYPE AND NUMBER OF PROJECTS INSPECTED

Slag Type	Number of Projects
Air cooled blast furnace	7
Granulated blast furnace	5
Combined blast furnace	2
Steam boiler	2
Basic oxygen steel	7
Open hearth steel	2
Combined steel	4
Slacker aggregate	1
Combined blast furnace and steel	7
Total	37

INSPECTION

Limits of projects selected for inspection were located on Ohio Department of Transportation highway maps. The general locations of these projects are shown in Figure 7. These sites were clustered about steel-making areas where slag is economically competitive with natural aggregates. It had been planned to inspect approximately 50 projects in all. However, some projects were deleted when certain conclusions became obvious after partial data collection. For example, inspection of projects with basic oxygen slag subbase was discontinued after it became obvious that this type of slag produced large volumes of tufa precipitate. A total of 37 projects, as shown in Table 1, were actually inspected.

On each project, underdrain outlets into catch basins and onto slopes inspected were observed. The presence of tufa was noted and a subjective evaluation made as to the severity of the tufa precipitate formation. Once it was determined that tufa was present on a single slag-type project, approximately one-fourth of the remaining underdrain outlets were observed. In cases where no tufa was seen, each outlet found was observed until the project was complete. On two slag-type projects, each outlet was observed and the limits of the presence or non-presence of the tufa noted.

FIGURE 7 Locations of projects inspected.

OBSERVATIONS

No tufa was observed on any project where the subbase was composed entirely of either air-cooled blast furnace slag, granulated blast furnace slag, or a combination of these. No tufa was observed on any project where subbase was entirely composed of steam boiler "slag."

Large volumes of tufa were observed on all projects where the subbase was composed entirely of basic oxygen steel slag. Within five to ten years after construction, underdrain outlets were almost completely blocked by the precipitate. The same held true for the project in which the subbase was composed entirely of slacker aggregate.

Tufa was observed on projects where the subbase was composed entirely of open hearth steel slag. In general, the amount of precipitate on these projects appeared to be significantly less than that on the basic oxygen projects.

Since 1977 Ohio Department of Transportation specifications have required a six-month stockpile aging of steel slags; however, this requirement was unrelated to tufa precipitate formation. In 1975 and 1976 the requirement was added on most projects by either plan or proposal note. Before 1975 no aging was required. Table 2 summarizes the sale dates of projects in which steel-making slag was used as the subbase.

When subbases were composed entirely or mostly of basic oxygen slags, no significant difference was observed between the volume of tufa on pre-1975 projects and on post-1975 projects. All projects in which subbases were composed entirely of open hearth slag or of a combination of open hearth slags and blast furnace slags were sold after 1975. Therefore the amounts of tufa for six-month-aged versus non-aged open hearth slag could not be compared.

There was one observation of consequence on one of the "open hearth" projects. The subbase on this particular project was composed entirely of open hearth slag which had been stockpiled for approximately 10 years before use. Although some tufa was observed at a few underdrain outlets four years after installation, the volume was not great enough to cause concern.

At the time this report was written plans were being prepared for pavement rehabilitation projects on several of the steel slag projects inspected. The work includes partial pavement replacement as well as complete replacement of plugged underdrain systems. After construction these projects will be monitored to determine whether the steel slag subbases still produce significant tufa precipitate 10 or more years after installation. Based on observation of the one project under construction, it did not appear that the amount of material lost from the subbase during the tufa production process significantly affected subbase strength.

TABLE 2 SUMMARY OF PROJECT DATES FOR PROJECTS WITH STEEL SLAG SUBBASE

Year of Project Sale	Number of Projects
Prior to 1975 (no aging)	10
1975 and 1976 (6 month aging?)	2
After 1976 (6 month aging)	9
Total	21

CONCLUSIONS

1. Blast furnace slags used as subbase materials do not promote formation of tufa precipitate, owing to the insolubility of the complex silicates and alumino-silicates composing blast furnace slags.
2. Steam boiler "slag" used as subbase material does not promote formation of tufa precipitate, because this material is an acidic byproduct of coal burning power production and not a true slag.
3. Steel slags and slacker aggregate used as subbase materials promote formation of tufa precipitate in subsurface drainage systems because of the presence of free lime (calcium oxide) in these materials. Open hearth slag produces smaller volumes of tufa than other types of steel slag.
4. Short term (six-month) stockpile aging as currently required by Ohio Department of Transportation specifications does not reduce the amount of free lime in steel slags sufficiently to reduce the volume of the tufa precipitate.
5. Based on limited data it appears that long-term aging of open hearth slag reduces the amount of free lime sufficiently to keep the volume of tufa precipitate at acceptable levels.

RECOMMENDATIONS

1. Blast furnace slags and steam boiler slag may continue to be used as subbase material without hindrance.
2. Steel slags should not be used as subbase material where subsurface drainage systems are used unless it can be shown that exposed free lime has been removed from the graded material.
3. Further research should be conducted to determine acceptable levels of exposed free lime and the time required in stockpile aging to remove the free lime from various steel slags. Observation of new underdrain systems replacing plugged systems on pavement rehabilitation projects should be included in this research. The effect of washing stockpiles with water or spent pickling liquor to speed up the process should be included in this research.
4. Research should be undertaken to determine the amount and types of reactive calcium compounds present in recycled portland cement concrete and similar materials which have been linked to tufa-like precipitate formations.

ACKNOWLEDGMENTS

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The findings and opinions expressed are those of the author and do not consitute a standard or specification.

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