Waste Products in Highway Construction

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The use of waste materials and their products for highway construction is discussed. The general legislation, local liability, and research projects related to waste materials are outlined. The waste materials and products presented include waste paving, industrial ash, taconite tailings, waste tire rubber and products, building rubble, incinerator ash and products, waste glass, waste shingle and products, waste plastics and products, and slag. For each waste category, the legislation and restrictions, material properties, construction and application, field performance, and recycling at the end of service life, if available, are discussed. In addition, procedures for evaluation of and selection from waste alternatives are presented. Results from a survey sent to Minnesota city and county agencies are presented summarizing current practices in waste reuse for highway construction.

Highway construction projects depend on an adequate supply of aggregate and mineral filler. The demand for such filler used in highway construction has increased dramatically, especially where aggregate sources have been depleted, the quality of available aggregate is at a low level, or aggregate cannot be obtained because of mining restrictions, environmental protection regulations, or appreciating land values.

In contrast, enormous quantities of domestic, industrial, and mining waste are generated annually in the United States. An extensive effort to reuse wastes in highway construction has been made by researchers and engineers for almost a century; many reports and findings have been produced in this area (*1–55*). At present, there are seven reasons for an agency to consider the reuse of wastes:

- Shortage of aggregates,
- High cost of waste disposal,
- Commitment to the environment,
- Availability of virgin and waste materials,
- Local availability,
- Political pressure, and
- Environmental safety.

Four issues are fundamental in determining the appropriateness of using recycled waste materials in highway construction:

- Cost-effectiveness,
- Performance,
- Availability, and
- Prevailing political climate.

The high cost of processing wastes for reuse and the uncertainty of their performance and durability require that a better justification of their use be provided. This paper establishes an inventory of waste sources and provides technical definitions and sources of waste products. Based primarily on experience with their use in Minnesota, an evaluation of waste materials is given, along with the field performance of roads built with them. This report also summarizes survey results regarding the use of waste materials in Minnesota highway construction, based on responses from city and county engineers.

Although waste products have been used in all sizes of highways and roadways, a study of their application is particularly important in low-volume roadways. Many of the products outlined in this paper have not been tested adequately to define their field performance. By placing them in low-volume roadways, their properties can be determined and guidelines for their use can be refined.

A full report on waste materials in highway construction giving complete descriptions and properties of waste materials is available from the Minnesota Local Road Research Board (*56*). This paper serves as an overview of practices and materials available in Minnesota. Table 1 presents waste materials frequently used in Minnesota.

Waste Material Use and Treatment

Without modification in properties or addition of ingredients, a waste can be used as a mineral filler, additive, or aggregate in highway construction. Many wastes are potential admixtures, particularly when processed. The processed wastes generally can be obtained from a recycling or processing facility, and some have become commercial products. If the properties of a waste do not conflict with and are compatible with the properties of asphalt or portland cement, it is a potential aggregate for asphalt or concrete mix. A waste may also be directly placed as a base course if it satisfies the base material specifications and leachate requirements.

Proper evaluation of a specific waste material requires a basic knowledge of its physical and chemical characteristics. These properties must be obtained in order to meet the requirements for construction materials and the environmental protection regulations. Detailed material properties are available in the report by Han and Johnson (*56*). Table 2 gives waste products obtained from or reused in highway construction. Note that many of the materials have several uses.

Initial Screening

The initial screening of a waste material for its suitability in construction is a crucial start that leads to a cost-effective evaluation. The screening is based on various minimum criteria constrained by environmental regulations, construction requirements, geographic limitations, quantity of materials available, and local conditions.

TABLE 1 Waste Materials Frequently Used in Minnesota

Waste	Source	Condition	Aggregate
Flyash	Coal burning power plants	dust	Yes
Bottom ash	Coal burning power plants	fine sand	Yes
Boiler slag	Coal burning power plants	gravel	Yes
Steel slag	Iron and steel production plants	coarse	Yes
Bituminous coal refuse	Bituminous coal mines	fine and coarse	Yes
Dredge spoil	Navigable waterways	slurry	Yes
Taconite tailings	Taconite mines	slurry and fine	Yes
Building rubble	Demolition	coarse	Yes
Incinerator residue	Municipal incinerator	ash	Yes
Rubber tires	Automobile and truck tires	coarse and fine	Yes
Sewage sludge	Sewage treatment plants	slurry and ash	Yes
Glass	Container glass	coarse	Yes
Pyrolysis residue	Pyrolysis operations	char	Yes
Reclaimed paving waste	Highway constructions	coarse	Yes
Wood chips and sawdust	Logging-chipping operations	coarse	Yes
Battery casings	Automobile batteries	coarse	Yes

TABLE 2 Waste Products in Highway Construction

Waste	Description	Treatment	Use	Performance
Waste Paving Material				
Crushed Concrete	mix of stone, dirt, wood, brick, organic, & concrete	crushed, impurities removed	concrete mix aggregate; base aggregate	excellent
Pulverized Bituminous	mix of bituminous materials & aggregate	crushed	cold in-place recycling; as aggregate in washout areas	excellent
Industrial Material				
Flyash	finely divided residue w/pozzolanic properties	added to concrete to form flyash concrete (FAC); added to aggregate base for stabilization	additive; embankment or subgrade fill	in concrete, improved workability; reduces bleeding
Bottom Ash	finely divided residue from electric power generation		additive; embankment or subgrade fill	good
Mineral Material				
Iron Ore & Taconite Tailings	obtained from processing or pelletizing of iron ore & taconite	none	bituminous mix aggregate	suitable for thin overlays; requires 1-2% more AC than conventional mixes
Domestic Material				
Waste Tires	mechanically processed to achieve size & void reduction; may be left whole	shredded, chipped, or ground into crumb rubber additive (CRA); may be used whole	additive; embankment or subgrade fill; also used as safety feature in protective crash cushions	non-biodegradable; more durable than wood chips in fill; durability of CRA pavements still unresolved
Building Rubble	mix of concrete, plaster, steel, wood, brick, piping, AC, glass	must be crushed & sized, impurities removed	base or subgrade aggregate	good
Incinerated Sewage Sludge Ash	after primary treatment a liquid w/solids content of 5-10%	incinerated and incorporated into mixtures such as lime-flyash sulfate	additive; aggregate	adequate strength for road embankment construction
Waste Glass	obtained from roadside recycling	crushed, resulting in flat, elongated particles w/smooth surfaces & no porosity	base and subgrade aggregate additive; bituminous mix aggregate	has been show to improve thermal characteristics of paving mixtures
Incinerated Municipal Sludge	ash waste or incinerator ash residue; bottom ash consists of slag, glass, rocks, metals, and unbound organic matter	chemically fixed, forming treated ash pellets (TAP)	base, subbase, and pavement aggregates	TAP meets MnDOT specifications
Waste Shingles	obtained from roofing manufacturers	shingles ground for their aggregate and asphalt cement	additive in bituminous mixes	satisfactory; research continuing
Municipal Solid Waste Plastics	obtained from roadside recycling	melt-extruded into post & board shapes that can be applied to guardrail & fenceposts	safety features; fence, guardrail	flexural stress can be higher than concrete
Steel Slag	must be aged 6-7 months to allow complete expansion	none	base and subbase aggregate; concrete mix aggregate	good
Wood Chips and Sawdust	obtained from municipal solid waste sources	placed over polymer geogrid, spread, & compacted	lightweight fill	good

TABLE 3 Technical Feasibility for Aggregate Use in Base Courses

Rank	Class 1	Class 2	Class 3	Class 4
1	Flyash	Slate Mining Waste	Phosphate Slime	Iron Ore Tailings
2	Bottom Ash	Steel Slag	Rubber Tires	Sewage Sludge
3	Boiler Slag	Anthracite Coal Refuse	Foundry Waste	
4	Shingle Scrap	Taconite Tailings	Dredge Spoils	
5	Zinc Smelter Waste	Lead-Zinc Tailings	Bituminous Coal Refuse	
6	Gold Mining Waste	Phosphate Slag	Battery Casings	
7	Paving Waste	Incinerator Residue	Sulfate Sludge	
8	Waste Glass	Feldspar Tailings	Scrubber Sludge	
9	Blast Furnace Slag	Building Rubble		

The minimum environmental criterion is that a waste candidate must be nonhazardous. A waste product should be identified following the standard procedures in order to determine if it is hazardous. Detailed criteria for identifying hazardous waste can be found in *Minnesota Rules*, Parts 7045.0120 to 7045.0135 (*19*).

Material requirements for highway construction are the basic criteria for selecting waste materials. The potential waste replacements for cement or aggregate should satisfy the corresponding construction requirements. The waste material must be located within a reasonable geographic distance from a construction site or transportation costs will be prohibitive; 40 to 50 mi is considered a maximum economic hauling distance for truck transport and 100 mi for rail transport.

Technical Evaluation

The technical feasibility of using a waste in construction can be evaluated on the basis of its technical properties, including physical, mechanical, chemical, thermal, and optical properties related to specific highway applications. A simple evaluation system can be established by listing technical properties of waste candidates relevant to the application considered. In evaluating the number of properties relevant to the application, waste candidates are classified in the following manner: the more relevant properties a waste possesses, the more potential it has, and the higher it will be ranked. A four-class technical evaluation system could be used as follows:

- Class 1: wastes that have the highest potential for use and require a minimum of processing before use;
- Class 2: wastes that have a relatively high potential and require more extensive processing such as pelletizing and sintering;
- Class 3: wastes that have a relatively low potential for use and may require a formidable amount of processing, that may have some outstanding undesirable physical properties, and that may have rather nonuniform characteristics; and
- Class 4: wastes that have little or no potential and at best might be used in small amounts as filler or in very specialized applications.

A number of waste materials were evaluated for their potential use as aggregates using the four-class system, as shown in Tables 3 through 5. The wastes listed are also ranked in each class.

Overview of Current Statewide Practice

To obtain information on the current practices of waste reuse in Minnesota highway construction, a question-

TABLE 4 Technical Feasibility for Aggregate Use in Bituminous Mix

Rank	Class 1	Class 2	Class 3	Class 4
1	Flyash	Anthracite Coal Refuse	Rubber Tires	Sewage Sludge
2	Bottom Ash	Lead-Zinc Tailings	Bituminous Coal Refuse	
3	Shingle Scrap	Building Rubble	Foundry Waste	
4	Boiler Slag	Steel Slag	Battery Casings	
5	Zinc Smelter Waste	Feldspar Tailings	Iron Ore Tailings	
6	Gold Mining Waste	Copper Tailings	Slate Mining Waste	
7	Paving Waste	Phosphate Slag	Dredge Spoils	
8	Blast Furnace Slag	Phosphate Slime	Sulfate Sludge	
9	Waste glass	Incinerator Residue	Scrubber Sludge	

TABLE 5 Technical Feasibility for Aggregate Use in Concrete Mix

Rank	Class 1	Class 2	Class 3	Class 4
1	Flyash	Feldspar Tailings	Bituminous Coal Refuse	Sewage Sludge
2	Bottom Ash	Taconite Tailings	Building Rubble	Waste glass
3	Shingle Scrap	Anthracite Coal Refuse	Iron Ore Tailings	
4	Boiler Slag	Steel Slag	Zinc Smelter Waste	
5	Zinc Smelter Waste	Foundry Waste	Rubber Tires	
6	Gold Mining Waste	Incinerator Residue	Slate Mining Waste	
7	Paving Waste	Phosphate Slime	Dredge Spoils	
8	Blast Furnace Slag	Copper Tailings	Battery Casings	
9	Waste Glass	Lead-Zinc Tailings	Sulfate Sludge	
10			Scrubber Sludge	

naire was developed and distributed to all Minnesota cities and counties. Of the 198 questionnaires distributed, 79 cities and counties responded (40 percent). Beside providing answers to the specific questions, respondents also sent information concerning their own use of various waste materials in highway construction. The survey helped determine the latest trends, applications, and experiences in the use of waste materials (C. Han, unpublished data, 1993).

Among responding agencies, 39 had experience with the reuse of wastes in highway construction, 4 had experience in recycling, 1 is considering the reuse of waste, and 35 had no experience. As shown in Figure 1, many waste materials are being used by agencies, including paving materials with no salvage value, coal fly ash, waste glass, building rubble, coal bottom ash, sewage sludge, rubber tires, asphalt shingle, waste paper, mine tailings, and wood chips.

A total of 14 waste products are in use or are being studied experimentally in a variety of highway applications. Current practice indicates that a large number of respondents use waste paving materials, fly ash, and scrap tires. Most waste materials used were evaluated as at least competitive with the conventional materials. However, the use of steel slag, mine tailings, and scrap tires was considered uneconomical.

CASE STUDIES

Case 1: Shredded Tires, Benton County

Near Rice in Benton County, shredded tires were used as a lightweight fill material for State Aid Highway 21. This road is actually floating over swampy soils. The two-lane highway was originally constructed with a

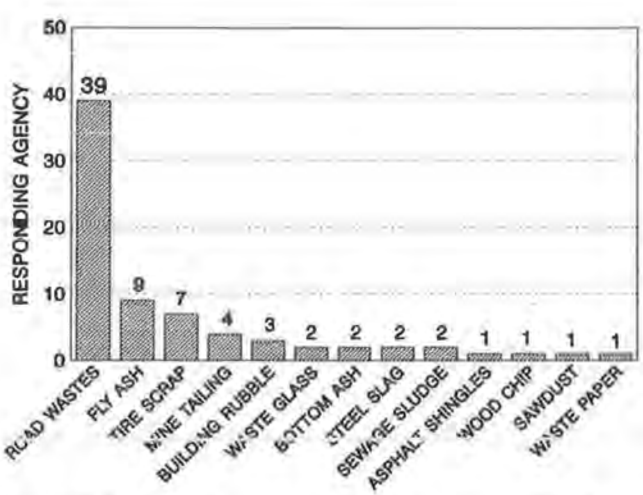

FIGURE 1 Use of waste materials in Minnesota highway construction.

sand-and-gravel subbase and was performing well. Over the years, the surrounding water levels increased to the level of the road. An attempt to raise the roadway with conventional granular fill overloaded the underlying 12-ft layer of peat and muck, causing an embankment failure. After performing a cost-benefit analysis, the county decided to use shredded tires as a lightweight fill material in reconstruction.

Reconstruction on the 250-ft section began in the fall of 1989. The first step was to excavate to a point $^1/_2$ ft above the swamp or marsh level. Next, a geotextile fabric was sewn together and positioned at the bottom of the excavation. Following the fabric, approximately 52,000 shredded tires were deposited in a 2-ft lift to a level of 3.5 ft below the top of the subgrade elevation. The shredded tires were compacted with bulldozers and front-end loaders until no further compaction was detected and were overlaid with another geotextile fabric layer. No moisture content was specified in the compaction process. Granular materials were placed over the fabric, and the fill was compacted using ordinary compaction. Finally, the new subbase and gravel base were constructed, and the roadway was allowed to settle naturally due to overburden for several months without traffic loadings. The bituminous surface was placed the following spring.

To date, the county road has not experienced any significant settlements and the bituminous surface is performing well.

Case 2: Waste Glass, Sibley County

Sibley County, the Office of Waste Management, and the Minnesota Department of Transportation combined efforts in a project to utilize waste glass with low-grade aggregate for better base materials. The mixed base materials were used to rebuild Sibley County Road 6.

Three hundred and thirty tons of mixed glass that were not suitable for normal glass recycling were used. The glass was crushed with a low-grade aggregate to make a Class 5 gravel base, containing approximately 10 percent glass. The introduction of the glass not only reduced the percentages passing the $^3/_8$-in., No. 4, No. 10, and No. 40 sieves as anticipated, but it also increased the portion passing the No. 200 sieve by about 2 percent, which was not anticipated.

The mixed-glass aggregate was placed in a 1,000-ft test section on the 3.7-mi construction project. Three 3-in. lifts were placed topped with a final 4-in. lift of virgin Class 5 aggregate and sealed with a 3-in. bituminous surface. During construction, the surface was exposed to local traffic without incidence of tire puncture or any other apparent problems, and raveling of the surface appeared to be less in the test section constructed with the glass aggregate mixture. Except for more power and downshifting of gears required to place the mix because of greater friction, grading and compaction of the material went without incident.

Preliminary results indicate that low-quality "sandy" aggregate can be enhanced with the introduction of crushed glass, thus increasing the utilization of low-quality aggregate and disposing of an otherwise useless waste material.

Summary

An evaluation based on technical, environmental, and economic factors indicated that waste paving materials, fly ash, incinerator ash, waste shingles, rubber tires, and slag have significant potential to replace portions of conventional highway construction materials. The reuse of these waste products can be realized by a combined effort among agencies involved with waste management, natural source reserves, environmental protection, and highway construction.

Waste recycling and processing provide substitute construction materials as well as secondary waste materials. Specifications and construction procedures are needed for these materials to be applied to highway construction. It must be noted that highways and roadways are a long-term investment that must be both cost-effective and durable. Before widespread and general acceptance can be made of a waste product used in highway construction, it must be evaluated in a pilot project over a long period of time to quantify its actual performance. After pilot projects have been successfully constructed, specifications developed, and suitable long-term evaluations made, these materials can be routinely used. In the future, a complete closed-loop recycling process can be developed moving from product to waste infrastructure.

Waste processing by incinerating or composting also produces more and more secondary wastes. Under controlled construction, these processing residues can be utilized without imposing environmental risk. In this way, controlled disposal and construction are combined into one practice, thereby resulting in a cost-effective alternative to traditional means of road construction.

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