Recycling Asphalt Roofing Shingles in Asphalt Pavements

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Abstract: Up to one-fifth of construction and demolition waste in the Twin Cities metropolitan area consists of tear-off shingle scrap (TOSS), which is postconsumer roofing material that is removed when a home is reroofed. Of the 60,000 tons of TOSS generated annually in the metro region, more than 90% is potentially recyclable for use in asphalt pavement. At the beginning of 2010, the Minnesota Department of Transportation released a draft specification that would allow up to 5% TOSS to be used in asphalt. To fine-tune this specification, this study investigated how the addition of TOSS affects the low-temperature properties of asphalt mixtures used for paving roads, as well as the potential environmental benefits of using recycled materials in asphalt. The research showed that adding up to 3% TOSS resulted in no statistically significant differences in the low-temperature properties of the most commonly used asphalt mixtures. A preliminary environmental life-cycle assessment showed that asphalt mixtures that contain recycled shingles and reclaimed asphalt pavement consume less energy and produce fewer greenhouse gas emissions during the production process compared with an asphalt mixture with no recycled material. The highest reduction in these environmental impacts was estimated for the mixtures that used the highest amount of recycled materials. Based on this analysis, all the available TOSS in the Twin Cities metro area could potentially be recycled for use in asphalt pavement in the region. It is anticipated that the results of this research will provide critical information for the development of a standard specification for the use of scrap tear-off shingles in asphalt pavements in Minnesota. The research upon which this article is based was supported by a grant from CURA’s Faculty Interactive Research Program.

Asphalt pavements represent approximately 94% of the 2.5 million miles of paved roads in the United States. They are built using asphalt mixtures, which are composite materials that contain coarse and fine aggregates\(^1\) of specific sizes bound together with asphalt binder, a residue of the oil-distillation process. Asphalt binder is a highly temperature-susceptible viscoelastic material\(^2\) that flows like motor-grade oil at high temperatures and becomes as brittle as glass at low temperatures. As it ages, its properties change dramatically; the older the asphalt binder, the stiffer, more brittle, and more prone to cracking at low temperatures it becomes. The binder-aging process reduces the performance of asphalt pavements in climates like that found in Minnesota, where low-temperature cracking is prevalent due to very cold winter temperatures. The presence of cracks allows water to infiltrate the pavement and cause further damage in the form of potholes.

Recycled asphalt pavement is used extensively all over the world. According to the Federal Highway Administration, nearly 30 million tons of reclaimed asphalt pavement (RAP) is recycled and used as a component of new asphalt pavement every year, making RAP the most recycled material in the United States. However, due to the less desirable properties of aged asphalt binder in older pavements, the percentage of RAP added to new pavements has typically been limited to 20 to 30%.

Asphalt roofing shingles also contain asphalt binder, but it is stiffer than the binders typically used in paving applications. The Minnesota Department of Transportation (MnDOT) has sponsored several research studies during the past 15 years examining the potential use of recycled shingles in pavement applications. In 1996, the agency adopted a material specification that allowed up to 5% manufacturer waste shingle scrap (MWSS)—damaged or otherwise unusable shingles that manufacturers dispose of—to be used in asphalt pavement. Currently, approximately 70,000 tons of

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1 Aggregate is mineral material such as sand, gravel, crushed stone, slag, screenings, and mineral filler. Aggregates are primarily responsible for the weight-bearing capacity of a pavement.

2 Viscoelastic materials are materials that exhibit both viscous (like honey) and elastic (like rubber) characteristics under different conditions.
MWSS per year are generated from three shingle-production plants in Minnesota, of which 40,000–60,000 tons are recycled into asphalt pavements.

Recent research sponsored by the metro-region Solid Waste Management Coordinating Board and the Minnesota Pollution Control Agency suggests that up to 20% of construction and demolition waste in the Twin Cities metropolitan area consists of tear-off shingle scrap (TOSS)—that is, postconsumer roofing material that is removed when a home is reroofed. Approximately 60,000 tons of TOSS are generated annually in the metro region. Informal observations indicate that 90% or more of this roofing waste is potentially recyclable. However, unlike MWSS, TOSS poses a substantial recycling challenge. The asphalt binder in these shingles has been exposed to years of solar radiation, oxidation, and very high summer temperatures (155–175°F), resulting in the binder being substantially more brittle at low temperatures. Thus, it is critical to understand how the addition of TOSS affects asphalt-mixture properties in order to provide recommendations concerning how much TOSS can be added to asphalt mixtures without substantially affecting their cracking-resistance properties.

At the beginning of 2010, MnDOT released a draft specification that would allow up to 5% TOSS to be used in asphalt. Our objective was to conduct additional experimental work and analyses to help fine-tune this draft specification. Our work was performed in conjunction with an ongoing effort by MnDOT’s Office of Materials that was funded by the Minnesota Pollution Control Agency, and we used a common set of materials in both studies.

Methods and Findings
We investigated the impact on pavement-engineering properties when different percentages of recycled shingles were introduced into asphalt-pavement mixtures. In addition, we conducted a preliminary life-cycle analysis to evaluate the environmental benefits of recycling asphalt shingles for pavement applications.

Low-Temperature Properties. To test low-temperature properties of various asphalt mixtures, we obtained test materials from MnDOT’s Office of Materials that consisted of asphalt prepared with combinations of RAP, MWSS, and TOSS. MWSS and TOSS were added in quantities of either 3% or 5%. RAP was added in quantities of either 15% or 25%, which is typical for newly constructed asphalt pavements in Minnesota.3

For each asphalt mixture, we performed a creep test, which involves placing a constant load (pressure) on thin asphalt beams created from the various mixtures. These tests were conducted at temperatures that simulate the climate extremes found in Minnesota. For each mixture, we measured creep compliance, or the degree to which the asphalt resists deformation over time under a constant load. From this, we obtained two characteristics that are specific to asphalt materials: creep stiffness, a measure of how stiff the asphalt binder becomes under temperature extremes; and relaxation rate, an indicator of how fast stiffness decreases with time and makes the material less prone to cracking. For asphalt-pavement applications, the goal is to have minimal increase in creep stiffness and minimal loss in relaxation rate with the addition of shingles to the asphalt mixture when these mixtures are tested at cold-weather temperature extremes equivalent to those encountered during Minnesota winters.

Based on our analysis, we found that adding 15% or 25% RAP to the asphalt mixture increased creep stiffness and decreased relaxation rate statistically significantly compared with asphalts without RAP added. Adding 3% or 5% MWSS to the mixtures in addition to the 15% or 25% RAP resulted in no significant differences in creep stiffness or relaxation rate compared with 15% or 25% RAP mixtures with no MWSS added. Based on these results, it is reasonable to hypothesize that the addition of 15% or 25% RAP dominates the properties of the mixtures so that adding as much as 5% MWSS has little impact.

Adding up to 5% TOSS also resulted in no statistically significant changes in creep stiffness for 15% RAP and 25% RAP mixtures. With respect to relaxation rate, we observed no change for mixtures containing 15% RAP. However, we observed a significant decrease in relaxation rate for mixtures containing 25% RAP when only 3% TOSS was added. Because all new asphalt pavements in Minnesota contain various proportions of RAP, these findings support imposing a 3% limit on the addition of TOSS to asphalt mixtures.

Environmental Analysis. One of the most substantial effects of recycling shingles is the impact on the environment. According to the U.S. Environmental Protection Agency (EPA), life-cycle assessment—which considers the entire life of a product from cradle-to-grave—can be used to quantify the

cumulative environmental impacts throughout the entire life of a product. This method provides a general picture of the environmental benefits and consequences of various alternatives for products and processes.

Life-cycle assessment evaluates all stages in the product’s life, which includes raw-material extraction, transportation, processing, usage, and disposal. The analysis includes four steps:

1. Goal definition and scoping
2. Inventory analysis
3. Impact assessment
4. Interpretation

The first step involves defining the product, process, or activities and reviewing and establishing the environmental effects. In the second step, the material inputs and environmental outputs are identified. The inputs include water, energy, and materials, and the outputs include air emissions, solid waste, and wastewater. The third step involves assessing the potential ecological and human effects of the inputs and outputs. The final step involves evaluating the results from the impact assessment and inventory analysis and using these results for decision making.

For our analysis, we performed only steps 1 and 2 using a tool known as the Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE).4 PaLATE, a Microsoft Excel-based program, was created as a joint venture between the University of New Hampshire’s Recycled Materials Resource Center and the University of California at Berkeley. The program uses EPA data to quantify the environmental consequences from constructing and maintaining pavement. PaLATE also can be used to estimate the trade-offs between using virgin and recycled materials. The required user input includes data for initial construction-material quantities, maintenance quantities, and equipment use. This information is used to predict environmental effects such as energy consumption, water usage, global-warming potential, and various emissions.

Using PaLATE, our goal was to determine the environmental effects of using different quantities of shingles and RAP in pavement. We performed the life-cycle assessment on seven different mixtures: one with no recycled materials (the “control” mixture) and six with varying quantities of RAP and recycled asphalt shingles. We compared the environmental effects of mixtures with recycled materials with those of the control mixture. In this analysis, we assumed that recycled asphalt shingles contribute about 30% by weight of the total asphalt binder used to produce the mix, which decreases the total quantity of virgin binder required. Because insufficient pavement performance history is available to conclude otherwise, we assumed that the addition of recycled materials did not substantially affect the performance of the asphalt pavement during its service life compared with the control mixture with no recycled materials.

Using PaLATE, we modeled the potential energy use and carbon dioxide emissions for a 1-mile-long and 48-foot-wide (four-lane) section of pavement constructed with five inches of asphalt mixture and six inches of aggregate base. To estimate the environmental impacts of materials transportation—in this case, virgin aggregates and RAP—we assumed that the maximum one-way transport distance for any material was 30 miles. To account for the environmental effects of processing and construction, productivity values, fuel consumption, and engine capacity, we used values from the shingle-processing industry and construction-equipment manufacturers.

Based on our calculations, one mile of four-lane pavement containing no recycled materials would require more than 3,191 megawatt-hours of energy to construct—equivalent to the amount of electricity consumed annually by 277 average American households.5 In addition, construction would produce 702 tons of carbon dioxide (CO₂), a greenhouse gas that contributes to global climate change. This is equivalent to the annual CO₂ emissions from 128 standard-size American automobiles.6 We also determined environmental outputs for the other mixtures used to build the same road structure (Figures 1 and 2). All mixtures that contain recycled shingles and RAP consume less energy and release fewer tons of CO₂ to the atmosphere compared with the control mixture, which has no recycled materials. Not surprisingly, we estimated that energy use and CO₂ were reduced the most for the mixtures that contained the highest amount of recycled materials: 25% RAP combined with 5% recycled shingles (TOSS or MWSS). Both energy use and greenhouse gas emission for these mixtures were reduced approximately 10–20% compared with the control mixture. These values should be interpreted with caution because this was a very preliminary life-cycle assessment study intended only to provide a general estimate of the environmental differences between using pavement with shingles and pavement without shingles.

Although the PaLATE tool does not calculate the environmental impact on landfills, it should be mentioned that using recycled shingles in asphalt-pavement construction results in a substantial reduction in the amount of shingles that are sent to landfills. For each mile of five-inch asphalt pavement created with a mixture that contains 5% scrap shingles, we calculated that roughly 137 cubic yards of scrap materials would be diverted from a landfill. If the mixture contains 3% shingles, then roughly 82 cubic yards of scrap material would be diverted.

Conclusions and Policy Implications

It is anticipated that the results of this collaborative effort with MnDOT’s Office of Materials will lead to the development of a standard specification for the use of tear-off shingles in asphalt pavements in Minnesota. It will also provide information that will be used to develop future guidelines for removing, storing, and processing tear-off shingles to facilitate the recycling of all tear-off shingles in pavement applications.

Some simple calculations can provide a rough estimate of mixture production and miles of paved roads required to use the entire amount of TOSS that potentially can be recycled. The average house roof surface is about 2,000 square feet, which translates to approximately 2.7 tons of asphalt shingles per roof. A mile of pavement that has two 12-foot-wide lanes and a surface layer of asphalt mixture that is...
five inches thick requires approximately 9,000 tons of asphalt mixture. Assuming that 3% TOSS is used in the mix design, then roughly 270 tons of TOSS would be used per mile of road (equivalent to the amount of shingles on 100 roofs). To use all 55,000 tons of recyclable TOSS generated annually in the Twin Cities metro area (from approximately 20,000 roofs), a little more than 200 miles of roads—requiring 1.8 million tons of asphalt mixture—would have to be built. According to the Minnesota Asphalt Paving Association (MAPA), asphalt-mixture production in the Twin Cities metro area exceeds 2 million tons per year.

Minnesota’s asphalt-paving industry has been one of the first to use recycled roofing shingles in asphalt mixtures. According to the Construction Materials Recycling Association, all asphalt-mixing plants have the capability of adding recycled shingles during the asphalt-mixture production process, and four companies in Minnesota currently process shingles. According to MAPA, one of these processor sites alone can process about 20,000 tons of TOSS per year. Theoretically, then, both the processing capacity and consumption demand exist to recycle and use all the available TOSS in the Twin Cities metro area.

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