Energy Conservation and Global Warming Gas Reduction from the Use of Recycled Tires in Rubberized Asphalt Paving

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Summary

The use of rubberized pavement appears to offers a unique opportunity to take a major waste problem generated by the transportation sector and use it to reduce the consumption of resources (including materials and energy) by the same sector, while achieving significant performance benefits. Inclusion of rubber in the asphalt binder of concretes can enhance the performance characteristics of highway paving for some applications. From the resource utilization perspective these enhancements have two direct impacts 1) rubberized asphalt paving requires less thickness for a comparable performance to conventional paving thus reducing the consumption asphalt and aggregate; and 2) rubberized asphalt paving has been shown to last longer than conventional paving further reducing materials requirements.

Based on a range of appropriate applications and paving designs, ACEEE estimates that materials consumption can be reduced 3-7 million tons for asphalt and 40-90 million tons for aggregate. The production of both these materials is energy intensive requiring about 100,000 Btu to manufacture a barrel of asphalt and 56,000 Btu to manufacture a ton of aggregate. These energy savings are offset somewhat by the 1.9 million Btu required to produce a ton of the crumb rubber from scrap tires, but net annual energy savings of 4.6-9.8 trillion Btu are possible.

These manufacturing energy savings also translate into reductions in the emissions of greenhouse gases that are targeted for reduction by President Clinton's *Climate Change Action Plan* (1993). Based on the fuel mix required to manufacture these materials, a net potential reduction of 0.1-0.3 million metric tons of carbon equivalent (MMT) emissions can be avoided, which could contribute to the *Climate Change Action Plan* target of 108 MMT of reductions by 2000.

In addition to these manufacturing energy savings, other savings could be anticipated from: 1) reduced repaving due to the rehabilitation of worn pavement, 2) reduced production of raw materials, 3) reduced transportation and direct energy expenditures associated with paving operation, and 4) improved traffic flow resulting from reduced paving time and extended surface life.

Introduction

Worn out tires represent a major disposal problem for many localities. The tires cannot be placed in landfills because they will work their way to the surface breaking the cover on the landfill. Many tires never make it to landfills but are abandoned in piles breeding vectors such as mosquitoes and rodents, and posing the risk of tire-pile fires. The U.S. EPA (1991) estimates that approximately 285 million scrap tires are generated each year. Of that, 33 million tires are retreaded, another 22 million resold, and about 42 million tires have already found alternative uses. The remaining 188 million scrap tires are added to the growing problem of what to do with over two billion scrap tires.

One disposal option is to shred the tires and use them as fuel. While this does produce a product of value (energy in the form of heat, steam or electricity), it represents a low value use for a product with a significant investment in both material resources and energy.

Another option for worn tires is to produce crumb rubber and use it to produce asphalt-rubber paving concrete. Asphalt-rubber pavings were first tried in the mid-1960s, principally for use in rehabilitating deteriorated pavement. Since that time, a broad array of paving products has been developed with the knowledge of the material and application practice equivalent to standard paving procedures (Heitzman, 1992 and Morris, 1993).

Rubberized asphalt is produced by mixing 15-28 percent crumb rubber on a weight basis with petroleum asphalt (Robert & Lytton, 1987 and Heitzman, 1992). From a practical perspective the range of rubber content is 16-20 percent because greater crumb levels result in such high viscosities that it becomes difficult to work with (Stonex, 1994). The rubberized asphalt can then be spray applied or mixed with aggregate to produce a paving material that has been shown to have some beneficial properties, among them:

- ability to rehabilitate cracked pavements for which alternative techniques are not considered viable, significantly extending their life (Morris, 1993),

- the concrete has improved flexibility, adhesion and low-temperature strength characteristics that allow paving thickness to be reduced to one-half of conventional asphalt mixes in many applications. These products are applicable in both new road construction and for resurfacing (CalTrans, 1992). Preliminary tests suggest that the thickness can be reduced to as little as one-third the thickness of convention asphalt concrete (RPA, 1994),

- the concrete has superior wear and ageing characteristics allowing the pavement to last longer. Some studies report extensions of 25 percent or longer than conventional asphalt hot mix surfaces with some reporting a doubling of life (Heerkens and Jonker, 1993, and Heitzman, 1992).

- can be used to produce low noise, open graded pavements (Heerkens and Jonker, 1993), and

- superior traction characteristics (Heerkens and Jonker, 1993).

The addition crumb rubber to asphalt does not affect the recyclability of the pavement, nor does recycling appear to affect the beneficial characteristics of the rubberized asphalt (Heerkens and Jonker, 1993). Federal Highway Administration projects that the cost of asphalt-rubber concrete to 20 to 30 percent more than conventional asphalt concrete when it is routinely used in paving applications. Previous high-cost figures have been associated with small scale, experimental applications (Heitzman, 1993).

Several applications of rubberized asphalt have shown significant benefits:

- use as a friction top coat;
- use in the application of a stress absorbing membrane;
- use in the rehabilitation of degraded pavements; and
- use as a chip seal over existing pavement.

There are other asphalt paving applications, such as base coats for which the addition of crumb rubber does not appear to offer performance benefits (Heitzman, 1992, Morris, 1993 and Stonex, 1994). The author has been unable to obtain an estimate accurate of what fraction of the asphalt used for pavings goes to these four applications, some experts feel that it may be in the 20-40 percent range (RPA, 1994).

Analysis

Estimating the potential applications of rubberized asphalt paving is a difficult proposition. A large number of variables determine how an asphalt concrete is formulated including:

- specific use and weather condition that the pavement will encounter,
- physical characteristics of the binder and aggregate,
- site considerations such as soil conditions and base design, and
- desired performance characteristic of the pavement (e.g., noise, traction) (Heitzman, 1992 and Stonex, 1994).

In addition, the formulation of the paving materials will be different for new construction, repaving and surface rehabilitation applications

In 1992, 153 billion barrels of asphalt were produced for road paving applications (EIA, 1993). Based on the appropriate applications, range of reduced paving thicknesses, range of crumb rubber content, and extended pavement life, the annual consumption of paving asphalt could be reduced 12-27 percent (see **Table I**) if the same number of miles of highway were surfaced. This translates into a reduction in asphalt consumption of 3-7 million tons. The Asphalt Institute (1979) estimates that each barrel of asphalt requires 105 thousand Btu of energy to produce,[1] so an energy savings of 2-4 trillion Btu could be achieved.

Since the volume of asphalt concrete would be reduced, a corresponding reduction in aggregate would also be achieved. The asphalt content of a concrete is determined by several factors including asphalt and aggregate characteristics, and pavement application. In general rubberized pavements require slightly higher asphalt content. An average binder content for all asphalt pavements content is about 7.5 percent (Stonex, 1994). The resulting

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[1] This represents the energy consumed in production during the refining process and does not include the chemical potential energy inherent in the product itself.

Table I
Energy and Carbon Savings from Use of Rubberized Asphalt Paving

Aphalt Production		
Embedded production energy (a)	105,000	Btu/bbl
'92 Annual Production (b)	153	million bbl
	27.34	Million Tons (f)
est. '92 Energy Consumption in	16	TBtu
Aggregate Production		
Embedded production energy (a)	56,000	Btu/ton
Crumb Rubber Production		
Embedded production energy (j)	1.91	MBtu/ton
Tires Available annually (g)	188	million
Tons available annually @ 10 lb/tire	0.94	Million Tons

Rubberized Asphalt Paving			
Assumptions	Low	High	
Appropriate applications (h)	20%	40%	of asphalt consumption
Recycled tire content (e)	20%	16%	on total weight basis
Pavement lift thickness (i)	50%	33%	relative to
Extended road life (d)	25%	100%	conventional paving
Impacts			
Reduced Asphalt Consumption	12.0%	26.7%	
	3.3	7.3	Million Tons
Energy Savings	1.9	4.3	TBtus
Weighted Carbon Coeff. (c)	17.31		MMT/Quad
Carbon Emissions Reduction	0.033	0.074	MMT
Reduced aggregate consumption (l)	12%	27%	
	40.5	89.9	Million Tons
Energy Savings	2.3	5.0	TBtus
Weighted Carbon Coeff. (c)	51.12		MMT/Quad
Carbon Emissions Reduction	0.116	0.257	MMT
Increased crumb rubber consumptio	0.14	0.25	Million Tons
	28.2	49.3	Millions Tires
Increased Energy	0.3	0.5	TBtus
Weighted Carbon Coeff. (c)	51.12		MMT/Quad
Carbon Emissions Increase	0.014	0.024	MMT
Net Energy Savings	4.46	9.79	TBtus
Net Greenhouse Gas Reductions	0.135	0.308	MMT
Percent CCAP Target	0.13%	0.28%	
CCAP Taget (k)	108		MMT

Notes:
(a) The Asphalt Institute, 1979
(b) EIA, 1993b
(c) see Table III: assumes petro. fuel mix for asphalt, elec. for other
(d) Heerken and Jonker, 1993, and Heitzman, 1992
(e) Roberts & Lytton, 1987, Heitzman, 1992 and Stonex, 1994
(f) 5.595 bbl asphalt = 1 ton (a)
(g) EPA, 1991
(h) Stonex, 1994
(i) CalTrans, 1992
(j) see Table II
(k) Clinton and Gore, 1993
(l) assumes average binder content of 7.5% for all pavements (h)

reduction in aggregate consumption is 40-90 million tons. The Asphalt Institute (1979) estimates that aggregate production requires 56,000 Btu per ton, so energy consumption could be reduced 2-5 trillion Btu.

Table II

Energy Required to Produce Crumb Rubber

Crumbing of rubber (producing 10-20 mesh)

Production rate	4000	lb/hr
Motor capacity	2000	HP
Motor capacity factor	0.75	
Crumb rubber embedded energy content	954.38	btu/lb
	1.91	MBtu/ton

Source: Rubber Pavements Association, 1994

The increased use of rubberized asphalt would consumer 0.14-0.25 million tons of crumb rubber annually. Based on an average of 10 pounds of crumb rubber per tire, the 250 million tires generated annually would produce approximately 1.25 million tons of crumb rubber. It takes about two million Btu to produce each ton of crumb rubber (Rubberized Paving Association, 1994 see **Table II**). The increased crumb production would require 0.3-0.5 trillion Btu that would off set some savings from reduced asphalt and aggregate consumption. Based on these assumptions, a net savings from reduced asphalt consumption and increased crumb rubber production would result in 4.5-9.8 trillion Btu annually (**Table I**).

The mix of energy sources consumed by the petroleum industry is used to estimate weighted carbon coefficient for asphalt production to be 17.31 million metric tons of carbon equivalent (MMT) greenhouse gases for each Quad of energy reduction (**Table III**). Both aggregate and crumb rubber is assumed to be production by electricity so the national electrical generation energy source mix is used which produces a weighted fuel mix of 51.12 MMT per Quad (EIA, 1993a and Elliott, 1994). Adding the reductions from asphalt and aggregate

Table III
Calculation of Prorated Carbon Coefficient for Asphalt Production (a)

Sector Energy Consumption Data

	Fuel Mix						
	Nat. Gas	Distillate	Petrolem Residual	LPG	Coal & Coke	Other (d)	Net Electric (a Total
Sector Consumption (TBtu) (b)	1,673	12	48	4	253	646	440
Sector Consumption Fraction	54.4%	0.4%	1.6%	0.1%	8.2%	21.0%	14.3%

Weighted Carbon Coefficient for Sector 17.31 MMTCE/QBTU

Carbon Coeff. (MMTCE/QBTU)

	Gas	Distillate	Petrolem Residual	LPG	Coal	Other (d)	Electricity (c) Overall Nat. Avg.
Fuel carbon coefficients	14.54	19.97	21.66	17.26	25.45	0.00	51.12
Elec. Generation weighting							
Fossil Only (Btu consumption)	264				111	1,549	
	13.7%	0.0%	0.0%	0.0%	5.8%	80.5%	
Overall (Btu Consumption)	264				111	1,549	897
	9.4%	0.0%	0.0%	0.0%	3.9%	54.9%	31.8%

(a) based on methodology developed in Elliott, 1994
(b) EIA, 1993a
(c) assumes system eff. to be 31.6%
(d) other non-fossil fuel source (assumes net zero carbon emissions)

production savings and subtracting the increase emissions from crumb rubber production, a net reduction in carbon emissions of 0.135-0.308 MMT is possible (**Table I**). President Clinton's *Climate Change Action Plan* calls for a reduction in annual emissions of 108 MMT by the year 2000 (Clinton and Gore, 1993).

Conclusions

The addition of crumb rubber to asphalt binders for paving applications appear to offer the potential for significant performance enhancement in some paving applications. This presents a unique opportunity for using a waste product from the transportation sector to benefit the same sector by producing better roads. In addition, rubberized asphalt represents an excellent opportunity to recapture the energy we invest in the production of the tires to reduce consumption of energy intensive new materials by extending the life of existing roads and reducing the amount of materials required to construct new road surfaces. The reduced net-energy required for paving materials production also results in a corresponding net-reduction in the emissions of carbon dioxide helping to meet our goals of national carbon reduction.

Further Work

This analysis understates the potential energy and carbon reduction from the use of rubberized asphalt because it considers only the production of paving materials. A more thorough modeling of paving activities and the associated energy costs associated with these activities is required.

One important application of rubberized asphalt is rehabilitation of deteriorated pavements. The experience in Arizona demonstrates that rubberized asphalt materials can be used to rehabilitate pavement that would otherwise require repaving. Repaving is costly, time consuming, and requires significant amounts of materials and energy (Morris, 1993). If the life of a pavement can be extended for several years as the Arizona experience indicates, repaving can be deferred with significant accompanying savings in cost, energy and materials.

In addition to the emissions reductions from reduced materials production, there would also be a reduction in direct energy consumption and emissions from the paving operations. Further emissions reduction (as well as energy and time savings) would also result from reduced traffic disruptions due to more rapid and infrequent paving resulting from the reduced thickness and longer pavement life associated with rubberized asphalt.

References

The Asphalt Institute (1979). *Energy Requirements for Roadway Pavements*, Lexington KY.

California Department of Transportation (CalTrans) (1992). "Asphalt Rubber Hot Mix-Gap Graded Thickness Determination Guide (Interim)," Sacramento, CA, March.

Clinton, President William and Vice-President Albert Gore (1993). *Climate Change Action Plan*, White House, Washington, DC.

Elliott, R. Neal (1994). *Carbon Reduction Potential from Recycling in Primary Materials Manufacturing*, American Council for an Energy-Efficient Economy, Washington, DC.

Energy Information Administration (EIA) (1993a). Manufacturing Energy Consumption Survey: Preliminary Estimates," *Monthly Energy Review*, September, U.S. Department of Energy, Washington, DC.

Energy Information Administration (1993b). *Petroleum Supply Annual 1992, Volume 1*, U.S. Department of Energy, Washington, DC.

Environmental Protection Agency, U.S. (1991) *Markets for Scrap Tires*, EPA/530-SW-90-074A, Washington, DC.

Heerkens, J. and C. Jonker (1993). "The application of rubberbitumen in the Netherlands," *European Asphalt Magazine*, 3/93.

Heitzman, M. (1992). *State of the Practice - Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier*, Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Morris, G. R. (1993). "True Cost Effectiveness of Asphalt-Rubber Raving Systems," *Use of Waste Materials in Hot-Mix Asphalt. ASTM STP 1193*, H. Fred Waller, Editor, American Society for Testing and Materials, Philadelphia, PA.

Robert and Lytton (1987). "FAA Mixture Design Procedure for Asphalt -Rubber Concrete," *Asphalt Materials and Mixtures*, Transportation Research Board, Washington, DC.

Rubber Pavements Association (RPA)(1994). Personal communication, Washington, DC.

Stonex, Anne (1994). Personal communication, International Surfacing, Inc., Chandler, AZ.