PAVING THE WAY FOR RECYCLING

Daniel Felperin
P.O. Box 1310
Middletown, CA 95461

INTRODUCTION

Roads have played an important part of human cultural and technical development. The first roads were constructed in southwestern Asia. The Romans used an extensive military road system during colonization of their empire. In today's world, engineered surfaces must withstand nature's elements and the immense stresses caused by heavy, multi-wheeled vehicles. Asphalt and "Portland Cement" are the two major types of concrete most commonly used in road paving.

Asphalt is perhaps man's oldest and most versatile engineering material. It has strong adhesive and bonding properties and is made up of a variety of viscous hydrocarbon tars (bitumens) which occur in soft, natural deposits (tar sands) or are derived from petroleum refining. Asphalt was isolated and used in Sumeria for ship building as early as 6000 B.C. It was used in Egypt for waterproofing as early as 2600 B.C. Throughout its early history, asphalt continued to be used as mortar, caulking and as a waterproofing agent in many applications (roofing, etc.). More recently, asphalt has been used for electrical insulators, hydraulics, erosion control, agriculture, acoustics and road paving.

Cementing materials have a similar history. Greeks and Romans were the first to manufacture concrete. They heated limestone to very high temperatures (calcined into lime) and combined it with water, sand and either crushed stone, tile, brick or variations thereof. Lime mortar does not harden under water. For those applications, Romans ground lime, volcanic ash or burnt, finely-divided clay tiles together. The ash reacted with the lime to produce what is called "Pozzolanic"[1] cement which will harden in water. Today the term describes cementitious material obtained by grinding natural minerals together at normal temperatures. In 1756, John Smeaton used proportions of clay and limestone and was the first to understand the properties of "hydraulic" (water reactive) lime. Portland cement was developed and introduced in 1824 by Joseph Asdpin. It was prepared by heating finely-divided clay and hard limestone in a furnace at 1400 degrees Celsius driving off all the carbon dioxide. The remaining fused slag was ground into a fine powder and mixed with a small amount of gypsum (hydrated calcium sulfate). The Glossary (page 7) describes common terminology used in the paving industry.

PAVEMENT COMPOSITION

Road pavement consists of a surface layer (course) which is engineered to provide wear and skid resistance. Beneath the surface course can be a number of other courses including crushed rock (stone), slag or gravel; asphalt-aggregate mixtures; or portland cement concrete. All these layers are piled on top a subgrade made up of compacted granular material or stabilized (packed) soils. In many instances it is desirable to directly apply asphalt to the subgrade to improve road performance characteristics. Untreated subgrades are usually designed for smaller volumes of lighter traffic. Each course must adhere (bond) to its surrounding ones. This is usually done by placing a "tack" coat of emulsified asphalt (an oil-water blend containing surfactants) on the surface of the top course prior to paving over it.

[1] From the village of Pozzuoli near Mt. Vesuvius where the volcanic ash was first found.

In general, pavement has three major components: aggregate, mineral filler and cement:

Aggregate-

Aggregate can be either naturally occurring or synthetic. Natural aggregate results from the erosion and degradation of exposed rock. It can be transported and deposited by wind (aoleian), water (fluvial) or earth movement. The mode of transport determines the shape and size of the particulate which is directly related to its overall suitability in paving mixtures. Particles are separated into diameter classifications. Sand is defined as those particles passing through a 2.36 mm (No. 8) sieve but retained on a 75 um (No. 200) sieve. Gravel particles will pass through a 75 mm (3 inch) sieve, but will be retained on a 2.36 mm sieve. Boulders are classified as particles with diameters greater than 75 mm. Aggregate is assessed by the following properties: cleanliness (free from extraneous debris); soundness (durability); toughness[1] (resist degradation under traffic loads); surface texture/particle shape (load bearing capacity); absorption (permeability); and cement affinity (matrix adhesion). Aggregate is sized, segregated by diameter (graded) and combined in varying proportions to achieve desired structural criteria. As a general rule of thumb, average particle size should be less than one half (1/2) the thickness of the pavement course.

Synthetic aggregate is a material which has undergone a physical and/or chemical change (sometimes called artificial aggregate). This generic group covers a wide range of material. The most prevalent are by-products of metal ore smelting. Non-metallic material which floats on the surface of molten metal ore (iron) is removed and recovered either by quenching with water or air cooling. They are relatively lightweight and display an unusual resistance to wear which are important considerations for road top layers. Process-fired material and rock are mainly argillaceous (clay-like) crystalline materials containing mostly aluminum silicates, sodium, calcium, potassium, barium, iron and others solidified in a mineral matrix. Artificial aggregate in paving construction is still quite new. The potential exists for other synthetic materials to be incorporated into various pavement blends which will meet and perhaps exceed engineering expectations and result in a more cost-effective and desirable road pavement.

Mineral Filler-

This material is a finely-divided (large surface area) mineral (derivative) of which at least a 70% of the particulate will pass through a 0.075 mm (No. 200) sieve. The presence of mineral filler has no cementitious value and tends to facilitate the placing and compaction (workability) of concrete. It can act as a partial replacement for larger structural aggregate when lower strength concretes are used. It takes up void space and bridges larger aggregate (mortar). Examples of common filler include pulverized limestone, hydrated lime, and finely-divided inert mineral particulate.

Cement-

Cement's primary goal is to bind aggregate into a stable mass capable of structural support. There are two major types: asphalt and portland. Asphalt cement is an organic, tar-like material produced by heating and blending various fractions of heavy petroleum distillates to achieve the desired physical and chemical properties. Portland type cement is primarily inorganic and is composed of calcium oxide (CaO), silica dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3). In addition, portland cement contains oxides of sodium, magnesium, titanium, manganese and potassium. Relative ratios of these mineral constituents yield cements with different mechanical

[1] Aggregate used in surface courses must have high toughness characteristics.

characterstics Portland cements undergo chemical reactions with the aggregate surface to create strong bonds giving internal strength to the mass. Concrete is a mixture of aggregate, water and cement which can be worked, formed and compacted into an engineered configuration to provide structural support.

FORMULATION

Road pavement formulation differs for asphalt and portland concrete. Steel reinforcement, long curing times and workability considerations make portland concrete less versatile of a paving material than asphalt concrete. Reinforced portland concrete does have higher compressive strength and is more durable. It can be an excellent base material for asphalt concrete (AC). AC is a high-quality, thoroughly controlled mixture of asphalt cement and well-graded, high quality aggregate thoroughly compacted into a uniform dense mass. It can be applied in either "hot" or "cold" forms. Hot mixing is done at a batch plant. This plant combines preheated aggregate and asphalt cement with sand and other mineral filler to produce a cementitious slurry (asphalt concrete). A "cold" mix is a blend of asphalt concrete which is slurried by the addition of a solvent (cutback). Once this "cutback" asphalt is applied, the volatile solvent evaporates leaving behind solidified paving material. Cold mixing is excellent for patching operations in cool climates.

APPLICATION

Portland concrete can be designed with specific advantages. This may include fast or slow hardening, low heats of hydration, chemical resistance, etc. The concrete is usually premixed and brought to the end use point and poured into the desired mold. The material is manipulated using mechanical means to detrain air and to reduce the void spaces. The curing time varies and care must be taken to avoid high internal temperatures resulting from the heat-liberating (exothermic) hydration reactions which can stress and weaken the structure. AC can be applied in layers over existing courses as well as treated and untreated subgrade. The AC is transported to the required location, placed and compacted. Cold mixing can be done on-site and does not require high temperatures during placement.

ECONOMICS

Profit is the bottom line for any viable business. It is directly linked to production costs which in turn are dependent upon the cost of energy, labor and materials. Raw materials are becoming more and more scarce. Scarcity drives up the cost of production and reduces profits. Therefore, it makes good business sense to look for ways to hedge rising material costs. One way to do this is by investigating sources and applications for retrograde materials. These reusable resources offer economic and environmental benefits.

WASTE MINIMIZATION

The Resource Conservation Recovery Act (RCRA) of 1976 was a landmark environmental law which required generators of wastes to determine if those wastes were "hazardous"[1] and mandated that hazardous waste streams be managed in such a manner as to mitigate any adverse impacts to human health or the environment. The regulations stipulated that generators were indeed responsible from the time the material became a waste until its final disposal (cradle-to-grave). Subsequent amendments (Hazardous and Solid Wastes, 1984) addressed the problems of toxics migration and groundwater contamination.

[1] These properties include ignitability, corrosivity, reactivity and toxicity as defined in 40 CFR Part 261.

Minimization encompasses four broad areas: source reduction, recycling, treatment, and residual disposal. Source reduction means substituting environmentally benign starting materials for hazardous ones. Recycling means utilizing wastes as useful products (paving materials). Treatment entails changing the physical and chemical nature of a hazardous substance to render it non-hazardous. Usually this implies making the material relatively inert with negligible hydrogeologic mobility. Residual disposal is the last option. This would refer to land disposal following the implementation of the previous three strategies.

SUBSTITUTION

Used materials (wastes) have the potential of being incorporated into road paving. Portland cement concrete formulation is primarily an inorganic process involving the reaction of aggregate, lime, metal silicates and water. Asphalt is organic in nature and relies on the fluids permeability into the aggregate and compaction. There are many ways to approach reuse of wastes as paving materials. One way is to employ gasoline contaminated soils as a subgrade course for FULL DEPTH ASPHALT PAVEMENT.[1] Oil sludges would also be good candidates for subgrade surface treatment prior to asphalt overlay (compaction). Some inorganic mineral sludges such as recovered sulfur sludges from hydrogen sulfide abatement systems (oil refining and geothermal energy) may have desirable properties for concrete mixes. Research has been done on both sulfur extended asphalt (SEA) and sulfur concrete. SEA has been shown to improve performance of roads made with lower quality aggregate. It has also improved age-hardened pavement . Sulfur concrete has demonstrated superior acid resistance, high impermeability, develops tremendous strength in a few hours, and can be placed all year round. Used asphalt concrete has been reformulated and placed again. Chipped rubber tires have also been tested as a potential substitute for aggregate and asphalt.

ENVIRONMENTAL REGULATION

In order to improve the quality of the environment, our leaders have passed numerous bills into law protecting U.S. natural resources. The RCRA Amendments of 1984 mandated that land disposal restrictions (LDRs) would take effect over a six year period. These LDRs require treatment standards on each type of federal listed waste. States may require that treatment standards be adopted for unlisted federal wastes (non-RCRA). The rationale behind treatment standards was to insure that landfilled hazardous wastes would not migrate and contaminate surrounding lands and water. Compliance with "land ban" is becoming more complicated and difficult. Waste minimization laws and regulations challenge generators to find environmentally cost-effective waste management solutions. Road paving lends itself well to recycling and treatment. Asphalt concrete has been made with used sandblast sand contaminated with metals. The AC permeates the sand particulate yielding a water repellent coating which encapsulates and isolates the contamination.

LIMITATIONS

Several obstacles impede full blown implementation of recycling hazardous wastes. In the case of road paving, regulators have difficulty condoning application of hazardous wastes directly to the land. Regulators are concerned about recycled hazardous wastes being released into the environment over time causing latent impacts. Regulators are also dealing with technologies which are new and untested. Industrial capacity and willingness to utilize these wastes is limited. Other industry concerns include indemnification, severable liability, material suitability for specific products, and economics.

[1] The term is registered by the Asphalt Institute with the U.S. Patent Office.

FUTURE OPPORTUNITIES

The paving industry has an opportunity to incorporate retrograde (hazardous) materials into their process. In many cases wastes are subjected to chemical and physical forces which alter and bind hazardous constituents in a manner similar to prescribed treatment technologies required under federal and state land disposal restrictions. There are also significant monetary incentives for both generators and end users. The generators can potentially sever long term environmental liability, save money on land disposal fees, taxes and in some cases transportation. End users will be paid for accepting retrograde materials and severing generator liability. They will also save money by reducing operating expenditures for raw starting materials. Development and implementation of business arrangements take time and there are legal obstacles to overcome. In the final analysis, all parties as well as the environment benefit from these efforts.

SUMMARY

Use of asphalt and cementitious materials have ancient origins. Modern day use revolves around road paving and construction. Pavement composition consists of aggregate and cement. Asphalt is organic and relies on adhesion and compaction for structure. Portland cement concrete is based on a chemical (hydration) reaction with lime, metal oxides, aggregate and water. Natural raw materials are becoming less available and have prompted investigation into the use of retrograde (waste) materials for paving applications. Environmental regulation is one major driving force behind waste minimization (source reduction, recycling, treatment (land ban), residual disposal). Obstacles that impede implementation of hazardous waste recycling for roads include: regulatory uncertainty and contradiction (hazardous materials intentionally being applied to land for paving purposes); and industry's willingness. Economics are shifting to make retrograde materials competitive with raw more expensive starting materials. When industry fully accepts the potential of these wastes, they will begin to assimilate them back into the process stream thereby making better use and reuse of our earth's finite natural resources.

REFERENCES

Asphalt Institute, Asphalt Paving Manual, third edition, Manual Series No. 8 (MS-8), College Park, Maryland, 1987.

Asphalt Institute, Asphalt Hot-Mix Recycling, second edition, MS-20, College Park, Maryland, 1986.

Asphalt Institute, Asphalt Overlays for Highway and Street Rehabilitation, MS-17, College Park, Maryland, 1983.

Asphalt Institute, Asphalt Handbook, MS-4, College Park, Maryland, 1989.

Asphalt Institute, Principles of Construction of Hot Mix Asphalt Pavements, MS-22, College Park, Maryland, 1983.

Asphalt Institute, Selection of Local Aggregates for Hot Asphalt Mixtures, Educational Series No. 7 (ES-7), College Park, Maryland, 1979.

California Health and Safety Code, Hazardous Waste Management Act. 1986, Division 20, Chapter 6.5, Article 7.7, Section 25179.1 et seq.

La Londe, W.S.; Janes, M.F.; Concrete Engineering Handbook, first edition, McGraw-Hill, New York, 1961.

McQuillen, J.L. et. al., Economic Analysis of Rubber-Modified Asphalt Mixes, Alaska Department of Transportation and Public Facilities, Junea, Alaska, 1988.

Neville, A.M.; Properties of Concrete, third edition, Pitman Publishers, London, 1981.

Puzinauskas, V.P.; Filler in Asphalt Mixtures, Research Report No. 69-2, Asphalt Institute, 1983.

Sulphur Institute, Sulphur Research and Development, Volume 7, pages 2-24, Washington D.C., 1983.

Sulphur Institute, Sulphur Research and Development, Volume 9, pages 2-20, Washington D.C., 1985.

42 U.S.C. 3251 et seq., Resource Conservation Recovery Act (PL 94-580), October 21, 1976, as amended by the Hazardous and Solid Waste Amendments, 1984 (PL- 98-616).

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Mr. Ken Monlux, President of Reed and Graham Environmental Services for his research assistance and moral support during this project.

GLOSSARY

COMMON TERMINOLOGY

Asphalt	A dark brown to black cementitious material in which the predominating constituents are hydrocarbon mineral tars (bitumens) which occur naturally or from petroleum refining.
Asphalt Cement	A highly viscous (thick) and sticky bitumen blend which adheres readily to aggregate particles and is used extensively for binding aggregate in hot-mix pavement.
Asphalt Concrete	A high quality, thoroughly controlled hot mixture of asphalt cement and well graded, high quality aggregate thoroughly compacted into a uniform dense mass.
Portland Cement	Mineral particulate usually produced by burning and grinding mixtures of limestone, clays and other metal mineral complexes together into a powder with excellent adhesive properties.
Concrete	Artificial stone-like material produced by mixing cement, sand, gravel, broken stone or other aggregate with water.
Cutback Asphalt	Asphalt cement which has been liquified by blending with petroleum solvents (diluents). Once applied, the solvents evaporate leaving behind the solid, fixed material.
Emulsified Asphalt	A suspension of asphalt cement globules in water Asphalt mixed with small amount of an chemical agent which forms one continuous phase. This liquid material can be prepared on site as a cold mix.
Aggregate	A hard granular material or mineral composition such as sand, gravel, slag, or crushed stone used for mixing in graduated fractions.

Course	Particulate retained on the 2.36 mm (No. 8) sieve.
Fine	Particulate passing through the 2.36 mm (No. 8) sieve.
Course-Graded	Having a continuous particle size distribution from course to fine with a predominance of course (larger) sizes.
Dense-Graded	Having a particle size distribution such that after compacting, the resultant void space between aggregates (expressed as a percentage of the total space occupied) is relatively small.
Open-Graded	Containing little or no mineral filler in which void spaces of the compacted aggregate are relatively large.
Well-Graded	Distributed from the maximum aggregate size down to filler. The resultant asphalt mix has controlled void content and high stability.