UPDATE ON WASTE RECYCLING STUDY

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A. USE OF TIRES IN HIGHWAY CONSTRUCTION

Background

Current estimates by the Environmental Protection Agency indicate that over 242 million scrap tires are generated each year in the United States. In addition, about 2 billion waste tires have been accumulated in stockpiles or uncontrolled tire dumps across the country. The Indiana Department of Environmental Management has documented over 40 stockpiles, spread over 25 counties, in Indiana containing millions of tires. It is estimated that approximately one tire per person is discarded each year, i.e., about five million waste tires are generated each year in Indiana. The current practice in waste tire disposal indicates that of the 1.9 million tons of tires discarded annually in the United States, 5% are exported, 6% recycled, 11% incinerated, and 78% are landfilled, stockpiled, or illegally dumped (1).

The composition of rubber tires makes them bulky, resilient, compaction resistant, and non-biodegradable. Disposal of large quantities of tires has accordingly many economic and environmental implications. Scrap tire piles which are growing each year pose two significant threats to the public: fire hazard - once set ablaze, they are almost impossible to extinguish; and health hazard - the water held by the tires attracts disease-carrying mosquitoes and rodents. Efforts to sharply reduce the environmentally and economically costly practice of landfilling/stockpiling have stimulated the pursuit of non-landfill disposal or reuse of waste tires. The composition of rubber tires, i.e., integrally combined rubber, synthetic fibers, steel, etc., has made it difficult to separate into ingredients for reuse and has lead to unique problems for disposal of tires. However, it has also rendered some useful mechanical properties to this waste product, which has made recycling of tires economically beneficial. Tires are elastic, lightweight, durable, and yield high BTU when incinerated. In addition, recycling of tires has a positive impact on environments. In view of potential economic and environmental benefits associated with the reuse/recycling of waste tires, the use of this product is being experimentally studied for a variety of applications.

Figure 1 shows the generalized tire cycle. From the manufacturer, tires are brought into use through an extensive distribution network to tire dealers. The dealers often specialize in one or two of the five major categories of use (i.e., cars and motor cycles, trucks, buses, aviation, and construction and agriculture). When the initial tread is worn down to the minimum acceptable standard, or when casing damage prevents the tire being used safely, the tire enters the inventory of used tires. These tires may then be sent to landfills, incinerators, or be chosen as suitable for retreading. Tires may be sent to tire processing facilities where they are sorted, and those found unsuitable for retreading or exporting may be reduced to smaller size chips through shredding, grinding to crumb rubber, or their ingredients may be separated through pyrolysis for reuse in manufacturing plants. The whole tires, tire sidewalls, shredded tire chips, crumb rubber, and reclaimed rubber may be used for a variety of engineering applications, which can broadly be divided into three categories: physical, chemical, and energy extraction. Some of the applications under each category are summarized in Figure 2 (2).

Recently, the senior author supervised a synthesis study (3) to identify those waste materials which have demonstrated technical, economic, and environmental feasibility for use in highway construction. The questionnaire survey conducted as part of this study indicated that of the 44 state highway agencies responding to the questionnaire, 30 states are currently using or experimenting with the use of rubber tires in a variety of highway applications. The study concluded that some of these applications show significant promise and should be projected for future use, which included: (a) use of crumb rubber in asphalt pavements, and (b) use of shredded tires in subgrade/embankments. However, it was recommended that further research would be required in certain areas prior to extensive use of these tire products in highway construction. Based on the conclusions of the synthesis study, two research studies have been initiated at Purdue University as part of Joint Highway Research Program: (a) Laboratory Study on Properties of Rubber-Soils; and (b) Synthesis Study on the Use of Tires Rubber in Asphalt.

Laboratory Study on Properties of Rubber-Soils

Construction of roads across soft soils present stability problems. To reduce the weight of the highway structure at such locations, wood-chips or saw dust have been traditionally used as a replacement for conventional materials. Wood is biodegradable and thus lacks durability. Conversely, rubber tires are non-biodegradable and thus more durable. It has been reported in the literature that some of the state highway agencies (e.g., Minnesota, Oregon, Vermont, and Wisconsin) have experimented with the use of shredded tires as a lightweight fill material. Their experience indicated that the use of tires in embankments is feasible and quite beneficial. In addition, inclusion of tire chips, which possess high tensile strength, in embankment fill is likely to increase the shear strength of soil. The use of shredded tires as a lightweight fill or as a soil reinforcement material seems very promising. However, information on this application of waste tires is severely lacking. Only a few limited laboratory studies have been reported in the literature.

This study, based on comprehensive laboratory testing and evaluations, will assess the technical, economic, and environmental feasibility of using shredded tires in construction of highway embankments as a lightweight fill or as a soil reinforcement material. The study primarily focuses on determining stress-strain and strength behavior (through static and dynamic triaxial testing) of compacted rubber-soils samples. Some of the variables to be considered include: size of compaction mold, compactive effort, tire chip sizes, soil/chip ratio, and type of soil. In addition, the study will briefly analyze economic and environmental aspects of this application of waste tires. The findings of this study will allow the Indiana Department of Transportation (INDOT) to determine economic benefits and environmental consequences of using shredded tires in highway embankments.

The researcher is currently engaged in conducting various tasks required to accomplish the research objectives, including: review of available information; collection of rubber and soil samples; modification/manufacture of testing equipment; compaction testing of rubber-soils specimens and shear testing of soils. The review of available information encompasses: current practice in generation and disposal of waste tires; field experience in the use of shredded tires; composition of rubber tires, including laboratory and field data on leachates; soil reinforcement of fine and coarse grained soils - mechanism and existing materials/techniques; available lightweight fill materials; resilient modulus of subgrade soils; compaction and shear behavior of soils with inclusions; effects of oversize particles on stress-strain and strength behavior of soils; and laboratory testing of large size specimens. Shredded tire samples of sizes ranging from sieve #4 to 2 inches plus have been collected from various tire processing facilities. Two types of soils, representing fine and coarse grained soils, have been selected and prepared for testing purpose: (a) Ottawa sand - classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS) and A-3(0) as per AASHTO; and (b) Crosby Till - classified as sandy silty clay (CL-ML) as per USCS and A-4(0) according to AASHTO.

Major shear and compaction testing equipment has been obtained and compaction tests on control specimens and soils samples containing rubber chips of varying sizes are in progress. Preliminary arrangements for the shear testing of large scale rubber-soils specimens have been made and actual testing is likely to begin soon. The shear testing will include triaxial testing of compacted Crosby till and Ottawa sand samples with and without rubber chips to evaluate the effects of tire chip inclusions on the shear behavior of soils. The available test data will be analyzed and an interim report on the feasibility of using shredded tires in highway embankments will be submitted to the INDOT by May 1, 1992.

Use of Tire Rubber in Asphalt

The first concept of using rubber as an additive in asphalt started in 1950s and it was first implemented in the early 1960s (4). The purpose in using rubber-asphalt was to improve quality and to conserve natural resources by recycling waste materials.

Several states have developed pilot rubber-asphalt projects. Some of these states have expressed satisfaction with rubber-asphalt projects, whereas others had poor experiences with rubber-asphalt. The Wisconsin DOT has expressed the opinion that the use of rubber tires in asphalt has been a political decision rather than a technical one (5).

Some of the advantages claimed for rubber-asphalt are:

- reduce noise
- reduce stopping distance
- more durability
- reduce age hardening
- improve retention of aggregate, etc.

Since the 1970s extensive research has been accomplished on rubber-asphalt by state highway agencies. There is general agreement regarding the cost. Increase in cost ranges from 10 percent to over 100 percent with an average of 60 percent have been reported. Using the value of 60 percent, the cost of disposing of a single tire is $11. The increase in cost changes from one state to another and also changes from one project to another within the same state. Table 1 shows experience by New York State Department of Transportation (NYSDOT).

Table 1
Price Increases Relationship for Rubber-Modified Asphalt Compared to Conventional Asphalt (From 6)

Mix	Albany Co. Project	Delaware Co. Project
1 % Rubber	+ 50 %	+ 114 %
2 % Rubber	+ 50 %	+ 114 %
3 % Rubber	+ 50 %	+ 114 %
PlusRide, (a proprietary rubber product)	+ 50 %	+ 129 %

The factors that increase the cost are:

- Increased-asphalt cement binder content
- increased energy cost (higher mixing temperature)
- increased labor (sticky, hard to work with)
- Increased cleaning expenses
- equipment modification
- more time required to mix and test the samples

In addition, NYSDOT reports that adding rubber increases the air pollution which is environmentally not sound (6).

It was likely that increase in the use of rubber-asphalt will decrease the cost differential. However, other rubber tire disposals are being conventionally developed. NYSDOT (6) and ConnDOT (7) report that energy production facilities for tire scraps have been built in New York and Connecticut. The plant in New York State may consume all of that state's scrap tires. The plant in Connecticut is planning to use not only all Connecticut's scrap tires but those of neighboring states as well.

Nonetheless, there is a belief that rubber-asphalt will have a longer life span than conventional asphalt thus justifying a higher cost. This belief needs greater experimental justification.

The first part of the Purdue Synthesis study will address the usefulness of rubber asphalt products. The second part will consider the recycling and use of ebonite in asphalt. Little data on this product are available at this time.

B. WASTE FOUNDRY SAND IN HIGHWAY CONSTRUCTION

Waste Foundry Sand and its Generation

Waste foundry sand is generated by industries that use sand to form molds for castings. Figure 3 illustrates the primary sources of waste foundry sand. The preparation of molding sand involves, first of all, mixing and mulling operations, where sand is mixed with binder by some mechanical means. Mixing is the process of intermingling of unlike particles such that an average composition is attained, whereas mulling is the application of work forces to cause kneading, smearing, compression and shear such that the mulled product is uniform throughout. During the molding and casting process sand is formed into molds and metal is poured to make castings. Shakeout involves removal of molding sand from the casting but some sand still adheres to casting surfaces. This casting surface is shotblasted, grinded and finished to generate a portion of waste sand. Some sand is lost from the conveying system and is referred to as "sand spillage". Large amounts of waste are also generated from sand screenings. The mold and core lumps generated can be a significant quantity depending on the amount of core used in the molding process.

In many cases, most of the sand is reused. However, some new sand and binder is typically added to the used sand to maintain the molding properties of the sand and enhance casting quality. Although some sand is lost to spills and shakeout, an additional amount of sand must often be removed so the system can accommodate the portion of new sand that must be added. *This amount of removed sand, combined with the sand lost to spills, shakeout and sand not reused, becomes the "waste foundry sand."*

Figure 4 shows typical grain size curve of waste foundry sand. It can be seen that foundry wastes are typically uniform graded, consisting mostly of fine sand. Data from a very few samples show that these wastes fall into A-2 category according to the AASHTO classification.

Purpose of Purdue Research

Over the past few years, foundries have seen the cost of operation increase and the demand for castings decrease. Promulgation of RCRA (Resource Conservation and Recovery Act); landban; SARA (Superfund Authorization and Reauthorization Act), Employees' Right To Know Act; etc., have also resulted in costly land disposal facilities. These environmental regulations together with a current atmosphere of recession in United States are impelling foundries to consider innovative and constructive uses for managing their wastes. Constructive uses of foundry wastes may be included in landfill uses, embankments, subgrades, subbases, backfills, treatment of hazardous wastes, component in asphalt mixtures,etc.

Potential problem associated with its use will be its variability. Variability may occur due to differences in:

a) chemical composition of sand, and
b) type of molding process
c) types of metals casted in foundries

Different chemical composition of foundry sand are:

- silica (SiO_2)
- zircon-zirconium siliocate ($ZrO_2.SiO_2$)
- olivine-magnesium-iron-ortho silicate ($Mg2SiO_4 + Fe_2SiO_4$)
- chromite ($FeO.Cr_2O_3$)

Different types of molding processes are:

- green sand molding
- high pressure molding
- skin-dried and dry sand molding
- cement molding
- sodium silicate processes
- cold-setting process
- shell process
- hot-box or wet-mix process

The primary metals which may be casted in foundries are:

- steel
- gray iron
- ductile iron
- malleable iron
- aluminium
- brass
- bronze
- magnesium
- zinc.

These different types of chemical composition, metals casted and molding processes render a foundry waste to be either hazardous or nonhazardous. Although, the waste from the nonferrous foundry is classified under the regulations as “hazardous” because of presence of lead,copper, zinc, nickel and cadmium, a waste from a brass foundry (non-ferrous) may result in nonhazardous waste, depending upon the production process, particularly the frequency of new sand addition. Therefore a technically sound, rational approach on a case-by-case basis is required. The purpose of the Purdue research is to gather and synthesize existing information on spent Indiana foundry sands and to generate new data through experimental research on certain of these materials.

Research Methodology

A two year research program on the feasibility of using Indiana foundry sands in Highways has been initiated in the Civil Engineering Department at Purdue University in order to evaluate the potential environmental effect and physical/mechanical properties. The environmental/chemical tests will be provided by the sponsoring Indiana Cast Metal Association. The physical/mechanical tests which will be conducted at the Purdue University are:

- Grain size distribution
- Atterberg limits
- Specific gravity
- Compaction relations
- Compressibility
- Shear strength
- CBR
- Erodibility
- Permeability
- Durability
- Total organic content

With these tests and their analysis, substantial evidence will be accumulated relative to the suitability of foundry sand to be used by the INDOT.

Figure 1. TIRE CYCLE

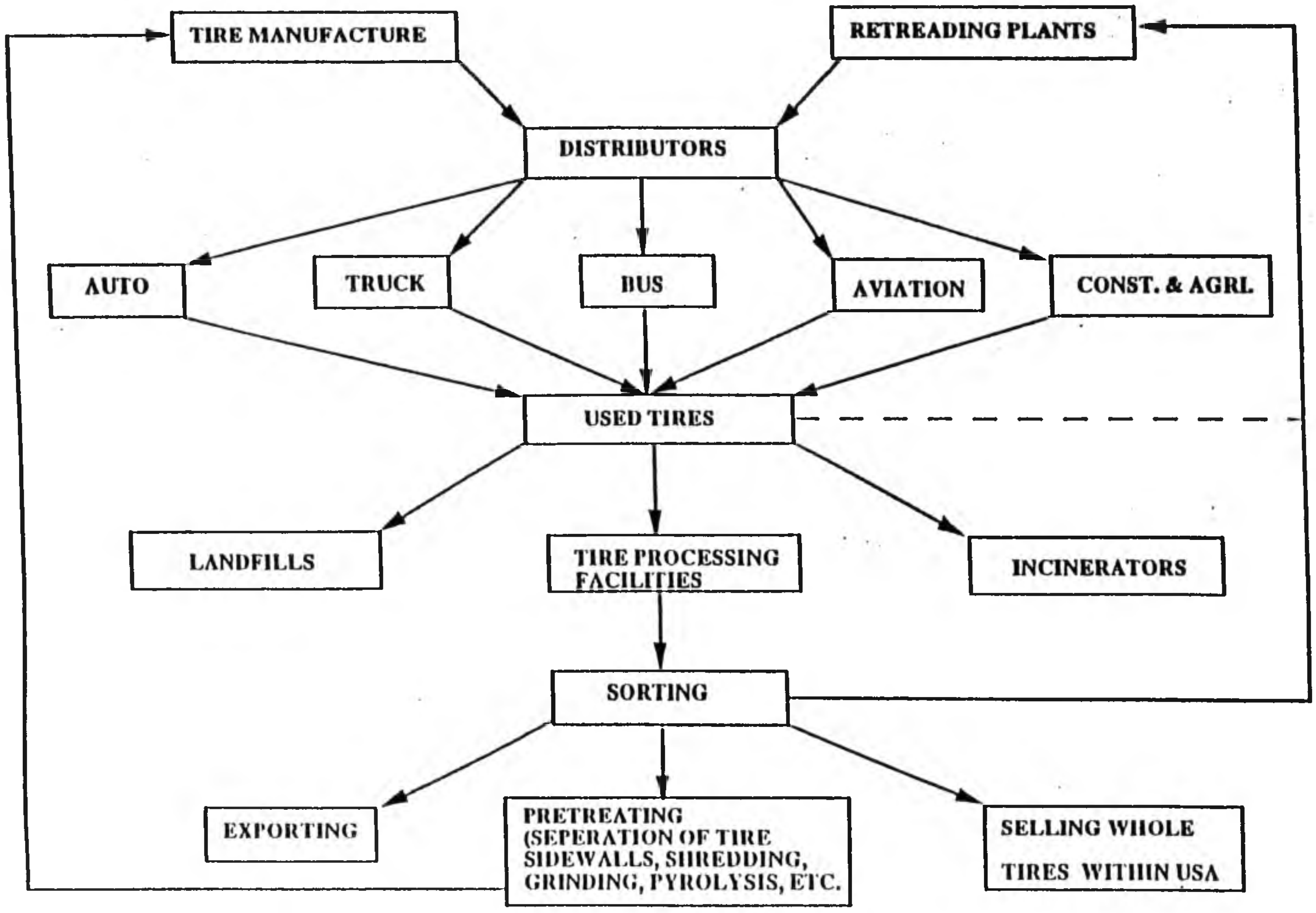
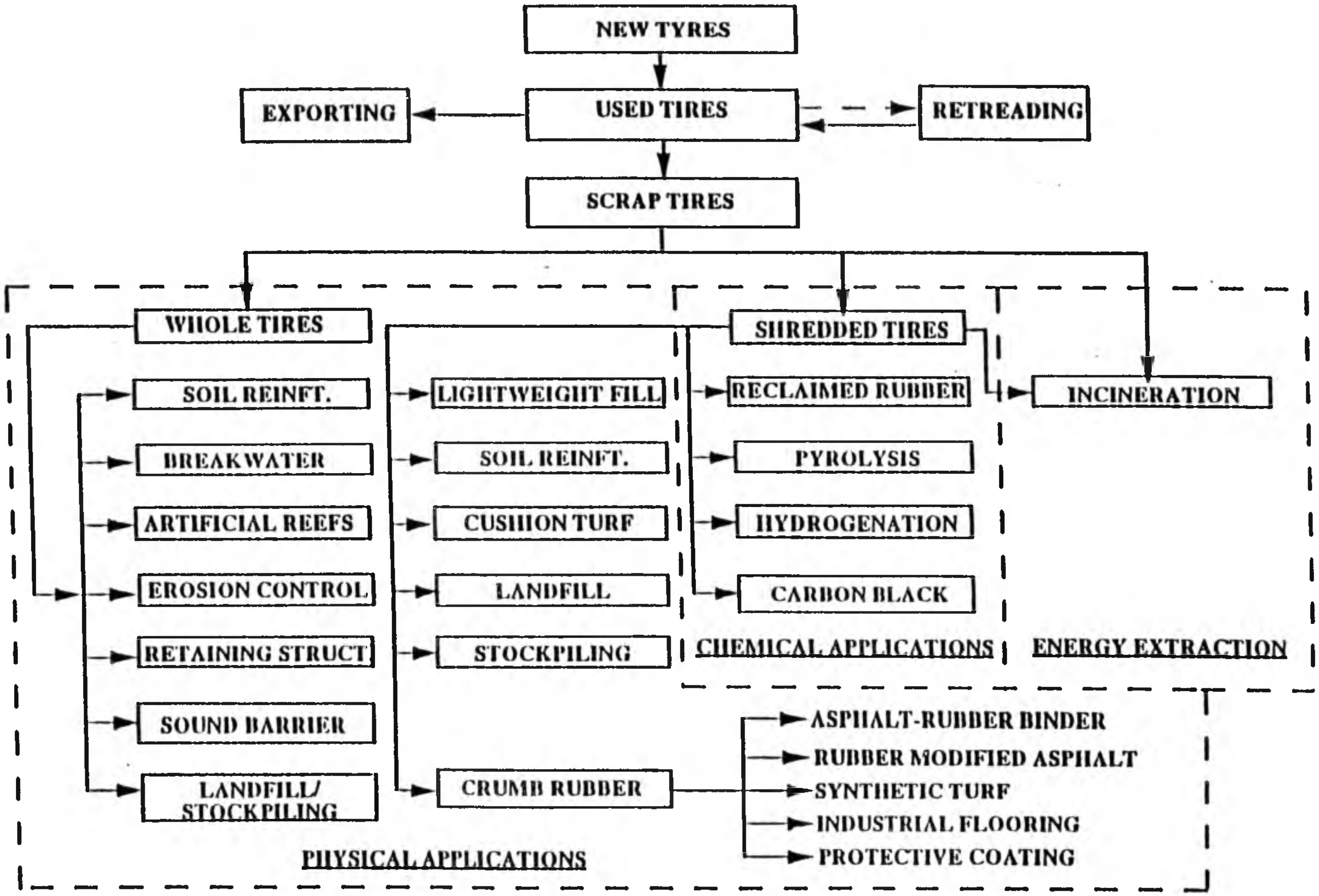


Figure 2

RECYCLING, REUSE, AND DISPOSAL ALTERNATIVES FOR SCRAP TIRES



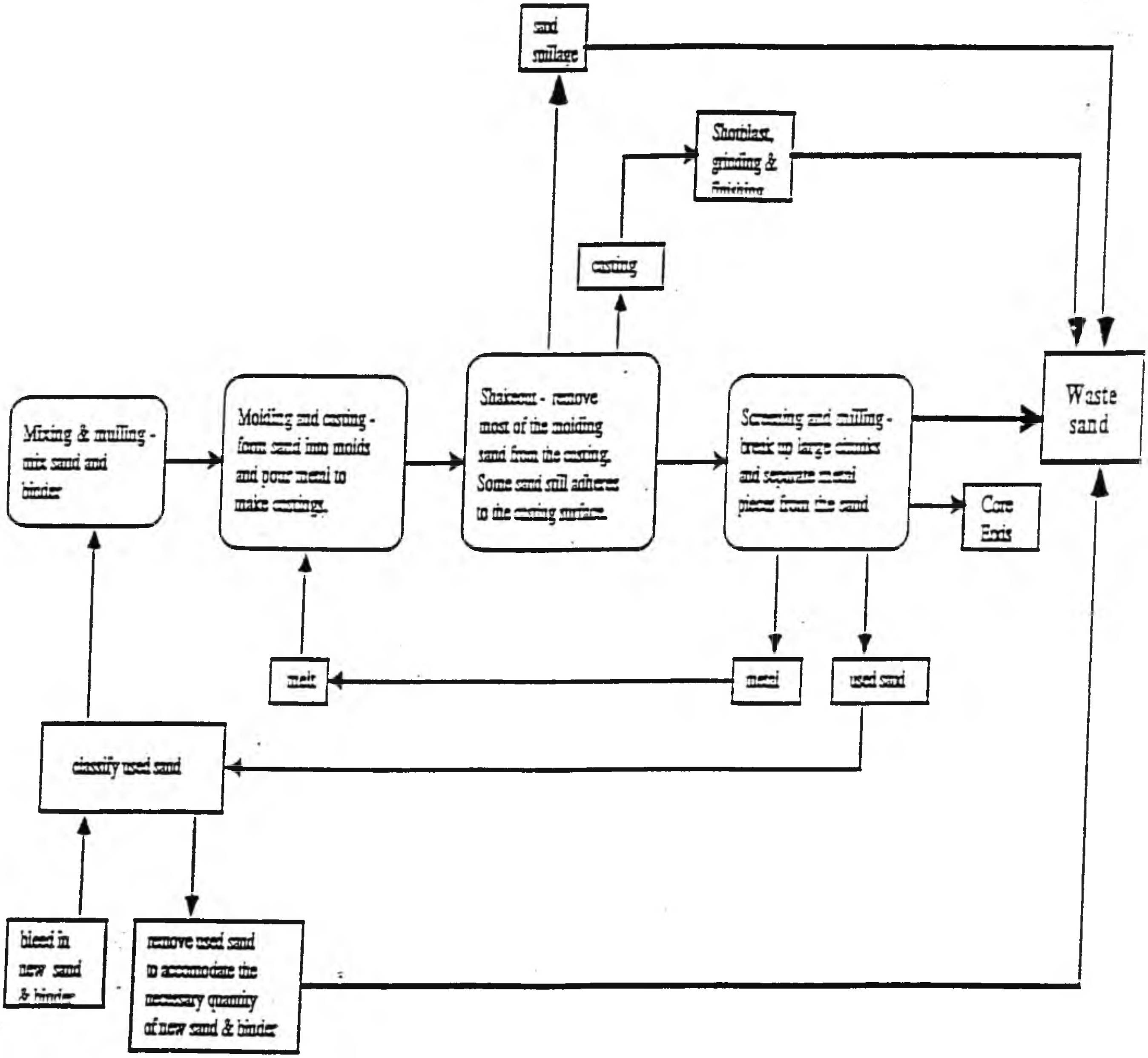
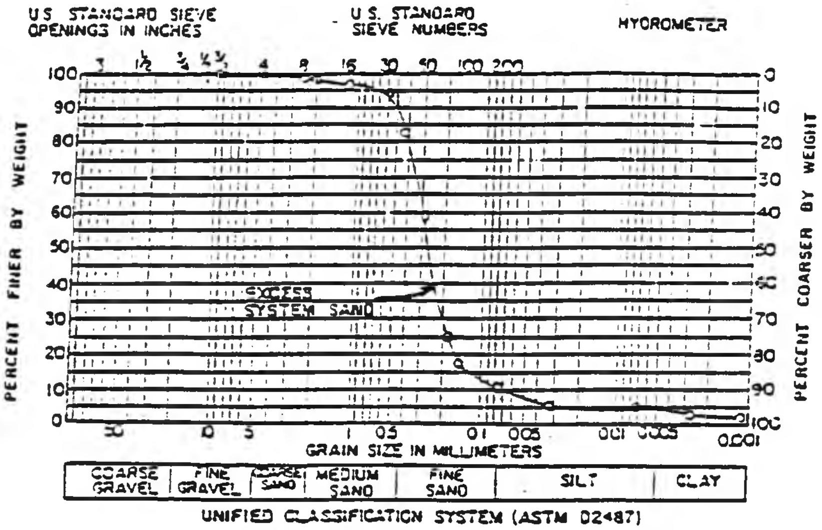


Figure 3. WASTE FOUNDRY SAND GENERATION (From 9)



CURVE	SAMPLE	% GRAV	% SAND	% SILT	% CLAY	SOIL CLASSIFICATION
0	EXCESS SYSTEM SAND	7	98.3	7.4	3.6	BLACK F-M SAND, TRACE SI, GR, CL

Figure 4. TYPICAL WASTE FOUNDRY SAND GRAIN SIZE CURVE (From 8)

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