

# Analysis of Industrial By-Products and Wastes usage for Highway Construction Projects

**Harshvardhan R. Godbole**, Research Scholar, Kalinga University, Raipur.

harshvardhan\_godbole@ymail.com

Dr. R.C.Charpe, Research Guide, Kalinga University, Raipur

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## Abstract

The necessity of achieving sustainable development is widely known, and it is being considered in almost all the required steps taken by the governments for the development of both developed and developing countries. Sustainable development helps achieving development of a nation, at the same time preserving the resources for future generation. Use of industrial by-products and wastes, which are normally disposed of in the vacant land, for replacing materials used for civil engineering purposes may help in achieving sustainable development by reducing carbon footprint emission. Due to larger consumption of materials for the construction of highways and roadways, use of industrial by-products and wastes as construction materials for highway and road may be a viable option for disposing, actually using, large quantities of them. In this perspective, industrial by-products and wastes such as waste foundry sand, fly ash and red mud can be used as highway construction materials. From the previous researches, it was found that soil-foundry sand mixtures amended with cement and lime can be used as highway subbase materials and they provide satisfactory results for unconfined compression tests and CBR tests. Even though these mixtures provide satisfactory mechanical properties, environmental suitability of materials has also to be investigated. This paper presents and discusses the environmental suitability of materials through the pH test and metal concentration test. The environmental suitability of the prepared mixtures was evaluated by analyzing the effluent collected during hydraulic conductivity tests. Laboratory leaching tests indicated that if these mixtures later come in contact with water that has been discharged directly to the environment (e.g., drainage through asphalt pavement), the quality of water will not be affected.

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## 1. INTRODUCTION

India, being a developing country, also requires lot of highways and village roads that are to be laid so as to improve the accessibility of remote areas. In this regard, there is an urgent need for exploring the industrial by-products and wastes suitable for possible use as highway and village road construction materials.

The industrial by-products and wastes such as

waste foundry sand, fly ash, and red mud are available in large quantities that are disposed on vacant land and, they form a threat to the green environment. Thus, use of industrial by-products and wastes as highway and village road construction material may serve the dual purpose of proving accessibility to remote areas but at the same time achieving sustainable development. It may also be considered to reduce the burden of the Manufacturing industries to take effort to dispose of their by-products and wastes.

In the present research investigation, experimental and analytical studies are carried out in order to explore the possibility of using industrial by-products and wastes such as waste foundry sand, fly ash and red mud together with stabilization materials like lime and cement as highway and village road construction materials. Different per cent of combination of these materials was considered in the present experimental investigations.

Dawson et al. [1](1995) assessed the suitability of industrial by-products generated in the United Kingdom to find their suitability of being used for pavement construction. Their structural properties and workability were also examined through laboratory and pilot scale experiments and related the performance of the material with the standard reference materials. Ranking of different materials has been made not only based on the structural performance but also based on the ease with which the materials may be used for achieving good quality pavement construction. The experimental study revealed that it is possible to use successfully the industrial by-products, either as aggregate or as binder or as both in the construction of road base layer.

Guney et al. (2006) [2] have carried out laboratory experiments on soil-WFS mixtures to test their strength parameters and hence their suitability to be used as highway sub-base materials. Cement and lime were used in their study as stabilization materials. The considered mixture proportions were compacted at different moisture contents and different compactive efforts in the laboratory. Tests such as unconfined compression, California bearing ratio, and hydraulic conductivity tests were carried out. Hydraulic conductivity tests on the effluent collected were used to evaluate the environmental suitability of the mixture proportions. Sub-base thicknesses were finally determined using the laboratory-based strength parameters. Curing time, comp active energy, presence of stabilizing materials such as lime or cement, and water content predominantly affected the strength of a mixture. They found that “the

resistance of WFS- based mixture to winter conditions is better than that of typical reference material. Leaching tests indicated that if the soil-WFS mixtures come in contact with water, the quality of water will not be affected.

Kalkan (2006) [3] has reported the results of the investigation carried out on red mud for useful purpose. The use of red mud for the stabilization material was investigated. This study pertains to study the effects of using red mud on the stabilization of soil. Unconfined compressive strength, hydraulic conductivity, and swelling were determined through experimental study. They report that compacted clay samples containing red mud and cement–red mud additives have a high compressive strength. They also report that the hydraulic conductivity and swelling percentage decrease compared to natural clay samples”.

Kirk (1998) [4] showed that waste foundry sand from ferrous industries can provide engineering properties that are suitable for construction of highway embankment. He also noted that Microtox™ bioassay test can be used to ‘screen’ the waste foundry sand to prevent their usage from contaminating the environment.

Kolias et al. (2005) [5] carried out experimental studies on the stabilization of clayey soil using fly ash. They reported that fly ash, together with cement, may be used to stabilize clayey soil. Type of soil, stabilization material used and age are the factors that are reported to affect the stabilization of clayey soil. Test results indicated that the compressive, flexural and tensile strength, CBR and elastic modulus increased considerably when fly ash was used for stabilizing clayey soil. They reported that when suitable measures were taken to reduce or avoid cracking of stabilized soil, they can be used effectively as a pavement material particularly with reduced thickness of asphalt layer.

Mast & Fox (1998) [6] evaluated “the use of waste foundry sand WFS as a highway embankment

material by conducting full-scale field demonstration. Geotechnical concerns such as deformation, strength, hydraulic conductivity, and ease of Construction were evaluated in their project. Three embankment sections were considered in their project and they were (i) section built with clay borrow, (ii) section built with natural sand, and (iii) section built with WFS. Their field demonstration project has shown that, from a geotechnical perspective, WFS can be successfully used as embankment fill material for highway projects.

Sen & Mistral (2010) reviewed the possibilities of using industrial wastes and by-products such as fly ash, blast furnace slag, cement kiln dust, waste foundry sand, phosphogypsum, waste plastic bags and colliery sand for the construction of village roads. The authors report that use of these materials improves the engineering properties of the soil and hence suitable to be used for village road construction.

Dhawan et al. (1994) showed that fly ash can be used as sub-base and sub-grade material. They carried out experiments to determine the properties of coal ash and soil combinations that could be used for road construction. Laboratory studies were carried out to determine the strength parameter of the combinations that were considered. The selected soils belonged to the groups such as CL, ML and CH as per Indian Soil Classification System.

Singh et al. (1996) conducted studies pertaining to the preparation of special cements using red mud obtained from HINDALCO (Hindustan Aluminium Corporation) Industries Limited, Renukoot, India. Three varieties of cements were investigated in their study. The effects of composition, firing temperature and duration on the cement properties were studied. Test results indicate that the cements made from lime + red mud + bauxite or lime + red mud + bauxite +

gypsum exhibited strengths comparable or superior to ordinary Portland cement (OPC). Nevertheless, those prepared using lime + red mud + fly ash did not have sufficient strength.

Test results indicated that the soils that were mixed with the bottom ash were stronger than those mixed with fly ash or pond ash and hence bottom ash from power stations might be used for road construction. It is suggested that the soils that are relatively poor in strength might be mixed with coarser coal ashes so as to get improved strength and bottom ash may be used as sub-base material in road construction”.

## 2. MATERIALS

### 2.1. Waste Foundry Sand

The waste foundry sand (WFS) was obtained from a locally available foundry industry in Chennai, Tamil Nadu India. The WFS was nearly black in color when obtained. The WFS was first sieved using a coarse sieve of size greater than 4.75 to remove possible lumps and other unwanted materials and dusts. The WFS was analyzed to determine its physical and chemical properties. The WFS used had approximately 99 per cent sand particles that passed through 2.36mm sieve. Sieve analysis was carried out to determine the gradation properties of WFS. Physical examination of WFS indicated that nearly all sand particles of WFS were of nearly same size. Physical observations indicated that, WFS had no significant cohesive properties. From the sieve analysis coefficient of curvature and uniformity coefficient were determined to be 1.16 and 2.52, respectively. Thus the WFS used in the presented study are classified as per Uniform Soil Classification system as poorly graded. WFS was subjected to chemical analysis so as to determine the chemical composition.

**Table 1 Chemical composition of WFS**

S.No.	Compound	%
1	Silica (as SiO <sub>2</sub> )	93.54
2	Alumina (as Al <sub>2</sub> O <sub>3</sub> )	1.89
3	Magnesium (as MgO)	0.10
4	Manganese (as MnO)	0.019
5	Iron (as Fe <sub>2</sub> O <sub>3</sub> )	1.03
6	Titanium (as TiO <sub>2</sub> )	0.17
7	Phosphorus (as P <sub>2</sub> O <sub>5</sub> )	0.018
8	Potassium (as K <sub>2</sub> O)	0.064
9	Sodium (as Na <sub>2</sub> O)	0.12
10	Loss on ignition	2.61

## 2.2 Fly Ash

Fly ash is a fine material that is precipitated from stack gases of industrial furnaces. It is reported that the characteristics and properties of the fly ash depend on the nature of the fuel used in the industry.

Fly ash is a fine powder comprised of spherical particles. The particles of fly ash are of nearly

spherical shape. The shape of the fly ash particles helps to achieve better flow ability and hence decreases water demand in the mixture. The fly ash is characterized by low specific gravity, uniform gradation, and lack of plasticity. The specific gravity of fly ash particles depends on their chemical composition, and it is reported that the specific gravity generally varies from 2.0 - 2.6. The pH of fly ash contacted with water ranges from 8 to 12.

**Table 2 Chemical Composition of the Fly ash**

S. No.	Compound	%
1	Total silica (SiO <sub>2</sub> )	50.40
2	Reactive silica	5.61
3	Alumina (Al <sub>2</sub> O <sub>3</sub> )	18.81
4	Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	16.61
5	Total calcium (CaO)	9.00
6	Free lime	3.92
7	Magnesium (MgO)	1.41
8	Titanium (TiO <sub>2</sub> )	0.28
9	Potassium (K <sub>2</sub> O)	3.46
10	Sodium (Na <sub>2</sub> O)	0.18
11	Loss on ignition	2.60

## 2.3 Red Mud

Red mud is an in-soluble product generated as

a by-product in the manufacturing of Aluminium using Beyer's process. Red mud is collected from the Aluminium industry named M/S Malco located at Salem, Tamilnadu, India.

**Table III Chemical Properties of Red Mud**

S.No.	Compound	%
1	Fe <sub>2</sub> O <sub>3</sub>	25.21
2	Al <sub>2</sub> O <sub>3</sub>	17.90
3	SiO <sub>2</sub>	7.62
4	CaO	22.41
5	Na <sub>2</sub> O	5.50
6	TiO <sub>2</sub>	6.9
7	K <sub>2</sub> O	0.08
8	Sc <sub>2</sub> O <sub>3</sub>	0.77
9	V <sub>2</sub> O <sub>5</sub>	0.31

### 3. EXPERIMENTAL STUDY

Experiments were carried out to determine California Bearing Ratio for totally 56 mixture proportions with various combination of industrial wastes/by-products and it was found by the researcher that most of the combinations give enough mechanical strength. In order to study the particle size distribution of combination of industrial wastes/by-products with the stabilizing materials sieve analysis test was carried out as per the code ASTM D422. The mix ingredients used satisfied particle size distribution limits prescribed by ASTM 147.

### 4. ENVIRONMENTAL SUITABILITY STUDY

In order to study the effects environmental suitability, totally nine mixture proportions are selected out of 56 mixture proportions which is considered for CBR strength parameter test. Samples were selected to study only the effect of waste foundry sand, foundry sand with cement, foundry sand with lime. The rest of the samples were chosen such that the mixture contains 70 per cent WFS. Since, from the CBR results it was interfered that 70 per cent use of WFS with varying proportions of fly

ash, red mud, with stabilizing agent which gives the higher CBR is considered as a best one among the mixtures.

The selected mix proportions were shown in Table 4. The materials used in the present experimental investigations are primarily granular. Hence, constant head permeability test was used in the determination of permeability of the mixtures considered. The test procedure as described in ASTM 5856-15 was used. The effluent from the permeability test (leachate) was collected on a regular basis and the samples were stored for further environmental analyses.

### 5. PH VALUE TEST

The PH value of the leachate is determined using a PH meter using the procedure described in EPA9045. The effluent collected during hydraulic conductivity test was used for PH value test. The leachate collected from the hydraulic tests is used to determine the nature of the leachate such as acidic or alkaline. The results of the pH tests carried out at different time such as 8 hours, 48 hours and 72 hours are graphically represented in Fig. 1

**Table IV Mix proportions considered**

	Industrial	Stabilizing

Sample ID	wastes/by-products			material	
	WFS	Fly ash	Red mud	Cement	Lime
S1	100	0	0	0	0
S2	95	0	0	5	0
S3	95	0	0	0	5
S4	70	25	0	5	0
S5	70	20	5	5	0
S6	70	15	10	5	0
S7	70	25	0	0	5
S8	70	20	5	0	5
S9	70	15	10	0	5

**Notes:** W.F.S - Foundry sand; F.A. – Fly Ash; R.M 1 and R.M 2 are designate the specimens with 5% Red mud, 10% Red mud; L and C are designate the specimens with 5% lime, 5% cement.

The pH test results indicate that in general, the mixture that contained only WFS had lower pH value than any other mixture considered in the present experimental study. Also, in general, for all the mixture proportions considered, the acidic nature was more after 8h and then reduced at 72h. The higher pH value of the mixture at 8h indicates that the leachate is alkaline in nature. This is attributed to the fact that the reactions of the ingredients are delayed.

At 48h, 72h the PH value of all the mixtures is lower than their corresponding values at 8h. The

reason for this observation may be that the ingredients might have reacted to form chemical compounds and resulted in a slight increase in the acidic nature of the leachate. After the reaction in complete, the acidic nature of the leachate was reduced and this is indicated by the decrease in the pH value at 72h.

The discussions were made in the following lines with respect to the effect of ingredients such as WFS, fly ash, cement and lime on the pH values of the leachate at 72h.

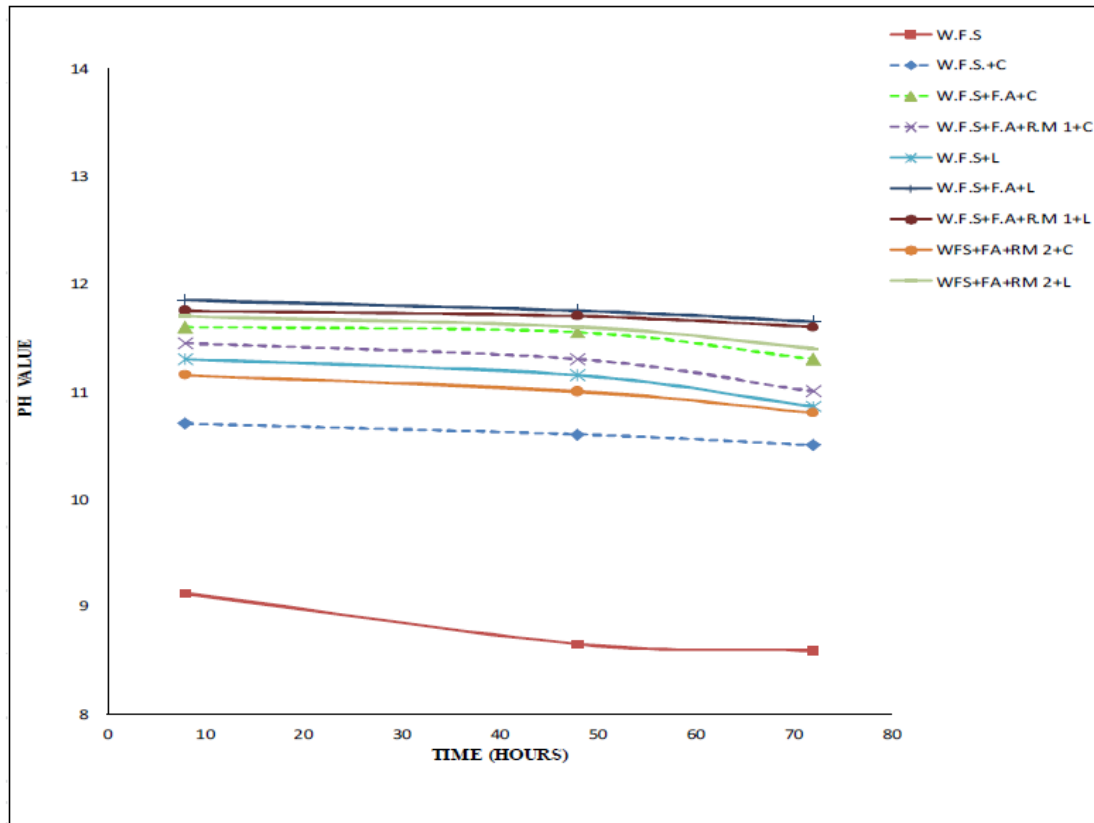


Figure 1: pH values

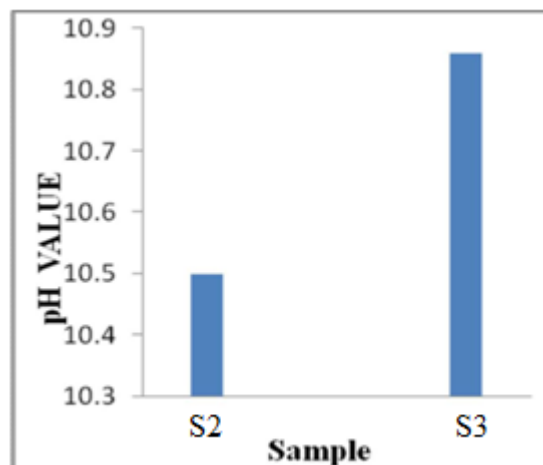
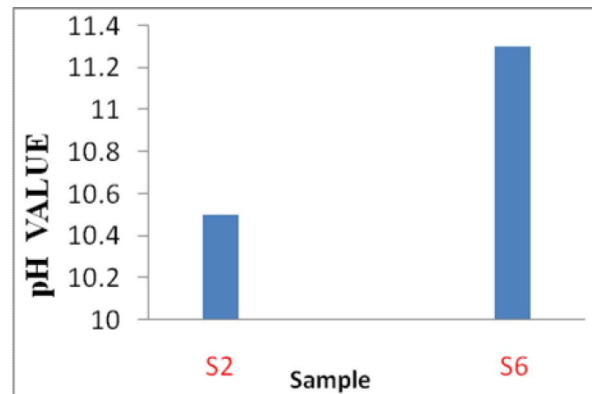


Fig. 2 Effect of Stabilizing Agent on pH value

The effect of stabilizing agents on the pH value of the mixture is shown in Fig. 2. It was inferred from this figure that, when compared to lime, the pH value of the leachate was reduced when cement was used as the stabilizing agent. This may be attributed to the

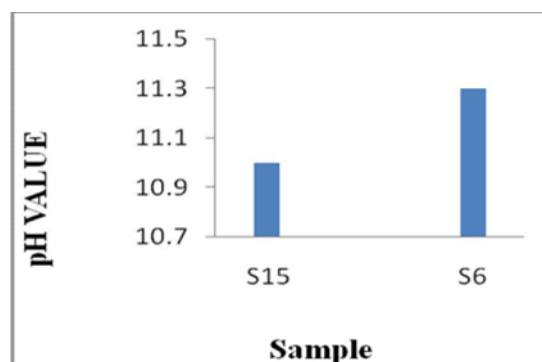
reason that, the chemical compounds found in the lime are base in nature. However, the difference between the pH values is very marginal. The effect of per cent use of fly ash in the mixture on the pH value is shown in Fig. 3.



**Fig. 3 Effect of WFS and Fly ash on pH value**

It is inferred from Fig. 3, So that by comparing the pH test results of the mixtures S2 and S4 the effect of WFS and fly ash on the pH value of the mixtures is increasing. The variations of percent use of WFS and fly ash seem to have slight increasing effect on the pH value of the mixtures.

The effect of red mud present in the mixture on the pH value of the mixtures may be inferred by comparing the pH test results of the mixtures S4 and S5. The comparison is shown in the Fig. 4.

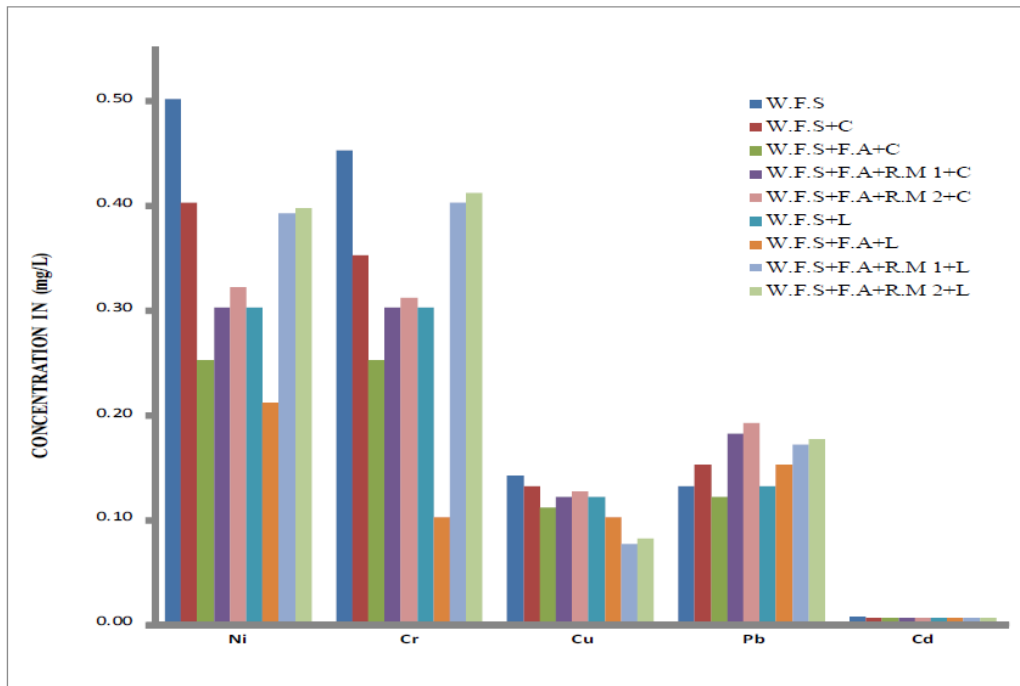


**Fig. 4 Effect of Red Mud on pH value**

From Fig. 4, it was observed that the presence of red mud in the mixture lowered the pH value of the leachate. This may be attributed to the reasons that the compounds such as  $Al_2O_3$  and  $SiO_2$  are present in the red mud and they impart acidic nature to the leachate. However, the difference in the pH values is marginal. The effect of red mud on the pH value of the mixtures might be known when different percentages of red mud are considered to make useful inferences.

## 6. METAL CONCENTRATION TEST

In order to study the concentration of heavy metal in the leachate obtained, metal concentration after 72 hours was determined using the procedure described in EPS3050. If any heavy metals are present in the leachate because presence of heavy metals may threaten the suitability of the environment for living organisms. The samples considered for metal concentration test is same as PH test. The amount of leached constituents from waste foundry sand based mixture with various proportions of fly ash, red mud with stabilizing agents are shown graphically in Figure 5



**Figure. 5 Results of Metal Concentration Tests**

**Notes:** W.F.S - Foundry sand; F.A. – Fly Ash; R.M 1 and R.M 2 are designate the specimens with 5% Red mud, 10% Red mud; L and C are designate the specimens with 5% lime, 5% cement.

The results of the metal concentration tests indicate that the presence of heavy metals that are harmful to the environment present in the leachate are within the permissible limits. And hence it may be concluded that the use of combination of the industrial by-products and wastes considered in the present study whose leachate (that may be generated during rain) when comes in contact with the environment may not affected the suitability of living conditions. The results of the metal concentration tests indicate that the presence of heavy metals that are harmful to the environment present in the leachate were within the permissible limits. The results also indicate that “the lime or cement amended mixtures result in lower metal concentrations, possibly due to decreased solubility of these constituents at high pH values as a result of agglomeration capacity of cement and lime”. And hence it may be concluded that the use of combination of the industrial by-products and wastes considered in the present study whose leachate

(that may be generated during rain) when comes in contact with the environment may not affected the suitability of living conditions.

## 7. CONCLUSION

Foundry system sand is a blend of silica sand, organic additives, and bentonite as a binder. Continued addition of binders and additives to the foundry system sand creates an excess volume that cannot be stored in landfills. Highway subbases are one of the largest application areas, and reuse of the foundry sand. The environmental suitability of the prepared mixtures of foundry sand and industrial by-products was analyzed through leaching tests. Laboratory leaching tests indicated that water passing through foundry sand-based mixtures will not become contaminated with undesirable compounds. Thus, if these mixtures later come in contact with water that has been discharged directly to the environment (e.g., drainage through asphalt

pavement), the quality of water will not be affected. The results indicated that the foundry sand utilized in this study satisfies the environmental limits and can be safely used as a component in highway subbases.

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