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# Construction of a Gravel Road Using Bauxite Residue

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**Abstract:** Results from research efforts over many years by the Highway Laboratory of Civil Engineering Department of Aristotle University of Thessaloniki (AUTH) and other academic or research institutions on behalf of "Aluminium of Greece" have demonstrated the potential use of bauxite residue in the construction industry as bricks, in the ceramic industry, for restoring abandoned surface mines and road construction. This paper details the construction of a gravel road using bauxite residue on the road "St. Nikolas-Kiriaki" in the site of the "Aluminium of Greece". The final layer included the addition of bauxite aggregates to provide an additional road carrying capacity. The aim of the project was to construct a trafficable surface for trucks and other vehicles with adequate resistance to heavy traffic loads and external factors as changing climatic conditions or soil erosion due to the rain. The construction is the right balance between technically excellent result and economically feasible. The prospect of using bauxite residue for similar road construction, or in general road construction, remains open.

**Key words:** Bauxite residue, embankment, by-product.

## 1. Introduction

Recycled materials that have suitable engineering, environmental and economic properties can be used as substitutes for natural aggregates or traditional materials in highway construction. These recycled materials are recovered materials from the transportation sector or secondary or by-product materials from industrial, municipal or mining sectors.

Bauxite residue (also called red mud) is the solid remainder of the bauxite industrial treatment by the Bayer process, which is universally applied for the aluminum production. In general, each tonne of alumina results in the production of approximately 0.5-2 tonnes of bauxite residue [1]. It is estimated that 1.0-1.6 tonnes of bauxite residue are generated per tonne and at all the world 85 alumina plants, around 145 million tonnes are produced annually [2].

Aluminum of Greece is the only aluminum refinery in Greece. It produces almost 700.000 tonnes of bauxite residue annually. The company exhibited a significant commitment to sustainable management of bauxite residue by investigating perspectives of reducing the quantities of the by-product disposal.

The Laboratory of Road Engineering of the Aristotle University of Thessaloniki has undertaken research projects to fully investigate the possibility of applying this by-product in road construction. During the first period of investigation (1993-95) the physico-chemical analysis of the material itself and the mechanical properties introduced into different mixtures were examined. The research aimed at defining a soil stabilization pattern by use of bauxite residue as a stabilizing material. For this purpose, soil types with poor characteristics inadequate for the construction of road embankments were chosen and their mixtures with bauxite residue were studied. The study revealed some strengthening properties of this material, specifically, the bearing capacity of the soil structure seems to increase up to 3 times with respect to its initial value.

During the second period of investigation (2001-2004), an experimental embankment was designed and constructed. The project was conceived after a long-time exploration of the material properties and its

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prospective performance. The construction stage of the project was planned in a way to build up a pilot structure by use of the by-product and to study the behavior of the earthwork under real loading conditions. The results of this investigation have demonstrated the excellent performance of the residue material in the construction of the embankment [3-6].

In this paper, the process of the construction of a gravel road used bauxite residue in the road "St.Nikolas-Kiriaki" in the site of the "Aluminium of Greece" is presented. The final layer is consisted of bauxite aggregates which provide an additional road carrying capacity layer.

## 2. Scope

Due to increasing amounts of bauxite residue material and decreasing landfill space, combined with concerns about environmental impact of dumping it to the sea, the perspective of reuse and recycling of this material has gained utmost importance. Use of alternative materials in road engineering is still at an experimental stage in Greece. Since Greece is a country disposing abundant quantities of natural materials for road construction, the incentive of using industrial by-products is not as strong as in other European countries like Sweden, Germany, Denmark, and Netherlands, where the recycling rate of materials attains almost 100%. A fundamental characteristic of highway engineering is the consumption and the utilization of huge amount of aggregate and raw materials in every construction project. An important incentive for the usage of the alternative materials in highway construction, especially in Greece, is the forthcoming construction of highway and national road projects.

Throughout the international literature, case studies of bauxite residue application in engineering projects are extremely rare mainly due to difficulties in handling, processing, transporting and laying the by-product. An investigation by the Laboratory of Highway Engineering of the AUTH designed and constructed a gravel road using bauxite residue. The aim of this project was to construct a smooth surface for vehicles with resistance to heavy traffic loads and external factors as changes in climatic conditions or soil erosion due to rain. The perspective of the construction of a gravel road in the area of the in the site of the "Aluminium of Greece” was the main idea of this project. The project was designed to study the behavior of the surface under real loading conditions. The key focus of this project was to develop technology and practices for the alternative use of bauxite residue that are economically viable and environmentally acceptable reducing, at the same time, the reliance of stockpiling and storage.

## 3. Laboratory Investigation

Bauxite residue is a complex material whose physical and chemical properties vary widely worldwide, depending primarily on the bauxite used and, to a lesser extent, the manner in which the bauxite is processed by the Bayer’s process technology. The principal constituent of bauxite is $Fe_2O_3$ and contains also five major constituents, namely $Al_2O_3$, $SiO_2$, $TiO_2$, $Na_2O$ and CaO with small quantities of numerous trace elements [7]. In Table 1, the chemical composition of the examined bauxite residue is presented and also the range of typical values encountered worldwide. Alkalinity tests yielded a pH value of 11.2.

Bauxite residue is a very fine red-colored material, having an average particle size of < 10μm. The physical properties were evaluated by laboratory analyses according to European Standards. Sieve-size analysis on dry samples confirmed the conventional grading of the material presenting a fraction passing the No200 sieve greater than 80% (Table 2). The material presents low to negligible plasticity (Table 3). This is mainly due to the uniformity of the grains which does not contribute to plastic performance of the residues.

**Table 1 Chemical composition of bauxite residue.**

| Chemical composition | Bauxite residue (%) (Greece) | Typical values worldwide (%) |
|---|---|---|
| $Fe_2O_3$ | 51 | 30-60 |
| $Al_2O_3$ | 15 | 10-20 |
| CaO | 13 | 2-8 |
| $SiO_2$ | 10 | 3-50 |
| $TiO_2$ | 5 | trace-25 |
| $Na_2O$ | 0.20 | 2-10 |

**Table 2 Sieve size analysis of bauxite residue.**

| Sieve | No10 | No16 | No25 | No40 | No80 | No100 | No200 | 45μm |
|---|---|---|---|---|---|---|---|---|
| % passing | 98 | 97 | 96 | 95 | 91 | 90 | 84 | 80 |

**Table 3 Physical properties of bauxite residue.**

| Atterberg Limits | | | Sand Equivalent | Specific Gravity |
|---|---|---|---|---|
| LL | LP | PI | SE | $\gamma s$ ( $t/m^3$) |
| 37 | 33 | 4 | 0 | 3.95 |

## 4. Proposed Composition

Four different compositions of bauxite residue were investigated with 10% or 20% of bauxite aggregates and the supplement of fly-ash (4%). Laboratory tests were conducted to determine compaction characteristics and bearing capacity of bauxite residue (Table 4). The following material composition of materials was selected after consideration of strength, life cycle, performance, construction handling and mechanical economy, confirmed by the experience gained from previous projects:

- bauxite residue = 90%
- bauxite aggregates ( d<1" = 2.5 cm) = 10%
- fly ash = 3%

The main benefits from this material composition have the great proportion of bauxite residue, the satisfactory workability and the resistance to erosion and other external factors.

## 5. Construction Process

The main components of the mixture (bauxite residue and bauxite aggregate) will be derived from deposits in the vicinity of the industrial area (see Figure 1). The issue of supply and transportation of fly ash is a serious problem, should be addressed properly on behalf of the success of the construction. Moreover, the proposed percentage of fly-ash was the minimum required from a technical outcome and the economy of the project.

It is important that the materials are clean and free of contaminants such soil, clay, derived from previous production. The mixture of the components will be on site just before the laying of the material. The homogenous distribution of the fly-ash within the mixture is very important. Moisture content of the

**Table 4 Mechanical properties of bauxite residue.**

| α/α | Material mixtures | $W_{OPM}$ (%) | $\gamma_{OPM}$ ($t/m^3$) | CBR | |
|---|---|---|---|---|---|
| | | | | 90% $\gamma_{OPM}$ | 95% $\gamma_{OPM}$ |
| 1 | BR/BA = 90/10 (%) | 25 | 1,76 | 67 | 85 |
| 2 | BR/BA = 90/10 (%) + FA(3%) | 25 | 1,76 | 82 | 110 |
| 3 | BR/BA = 80/20 (%) | 23 | 1,81 | 80 | 103 |
| 4 | BR/BA = 80/20 (%) + FA(3%) | 23 | 1,81 | 82 | 108 |

where: BR=bauxite residue, BA=bauxite aggregates, FA=fly ash

**Table 5 Results of compaction test (Proctor/CBR).**

| Number of blows | 10 | | | 30 | | | 65 | | |
|---|---|---|---|---|---|---|---|---|---|
| Displacement (0,01mm) | Resistance to penetration (mm) | Lo ad kg | Pressure Kg/cm² | Resistance to penetration (mm) | Lo ad kg | Pressure Kg/cm² | Resistance to penetration (mm) | Lo ad kg | Pressure Kg/cm² |
| 0.64 | 26 | 92 | 4.76 | 95 | 337 | 17.41 | 83 | 294 | 15.21 |
| 1.27 | 39 | 138 | 7.15 | 234 | 827 | 42.76 | 215 | 761 | 39.31 |
| 1.91 | 49 | 174 | 8.98 | 302 | 1067 | 55.14 | 368 | 1299 | 67.15 |
| 2.54 | 60 | 213 | 11.00 | 344 | 1215 | 62.78 | 461 | 1626 | 84.02 |
| 5.08 | 91 | 323 | 16.68 | 459 | 1619 | 83.66 | 697 | 2448 | 126.51 |
| 7.62 | 117 | 415 | 21.44 | 549 | 1934 | 99.93 | 860 | 3007 | 155.39 |
| TIMEΣ C.B.R. Values | | | | | | | | | |
| CBR1 | 11.00*(100/70.3) = 16 | | | 62.78*(100/70.3) = 89 | | | 84.02 *(100/70.3) = 120 | | |
| CBR2 | 16.68*(100/105.5) = 16 | | | 83.66*(100/105.5) = 79 | | | 126.51*(100/105.5)=120 | | |


**Fig. 1 The bauxite residue material.**


**Fig. 2 The construction of the road.**

**Fig. 3 The gravel road by bauxite residue.**

mixture should be very low (w<5%) otherwise there is a risk of chemical reaction before laying and potential failure during construction.

The first stage consisted of grubbing and clearing the existing surface of the local road, followed by water spreading. The main earthwork tasks were carried out by a grader and a loader, laying the material at a thickness 12 cm. and a length of 1200m. Before compaction, bauxite aggregates at a rate of 20 kg per square meter were applied on the gravel surface to improve bearing capacity. The compaction was carried out by a light non-vibrating roller of 8t.

The final outcome was very satisfactory, with the exception of some segments where excessive dust on the pavement surface created problems. This functional defect vanished after some time. The local road has been under traffic 18 months. The overall performance is very good and this proves that this secondary material can be used successfully in road construction.

## 6. Conclusions

A research engineering project carried out by the Laboratory of Highway Engineering Department of Civil Engineering, Aristotle University of Thessaloniki into the use of bauxite residue treatment in road construction, proved it suitability for construction purposes. The project constituted a technically sound solution for geotechnical construction and unbound pavements on the secondary network. High mechanical strength and resistance to external factors are obtained through a special engineering process.

The aim of the research was not only the implementation of a sound project from a technical point of view. Most important is the consideration of the economic issue. The issue of the construction cost, which is related to the cost of transport of the material, should be considered holistically, in a broader strategic framework for application in construction, at private companies, municipal and prefectural governments or even national planning.

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