Construction and Building Materials 61 (2014) 69–78

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Recycling foundry sand in road construction–field assessment

O. Yazoghli-Marzouk [a,*], N. Vulcano-greullet [a,1,2], L. Cantegrit [b,3], L. Friteyre [c,4], A. Jullien [d,5]

[a] CETE de Lyon, Département Laboratoire Autun, BP 141-Boulevard Bernard Giberstein, 71404 Autun, France
[b] CETE de Lyon, Département Laboratoire de Lyon, 25 avenue François Mittérand, 69500 Bron, France
[c] CETE de Lyon, Département Labopratoire Clermont-Ferrand, ZI Brézet, 8-10 rue Bernard Palissy, BP 11, 63014 Clermont-Ferrand, France
[d] LUNAM Université, Ifsttar, AME-EASE, Route de Bouaye, CS4, F-44341 Bouguenais, EU, France

HIGHLIGHTS

- We describe and discuss a real scale experimentation to study recycling feasibility of foundry sand in burgundy (France).
- We assess the same waste by monitoring an experimental site in real scale for 2 years.
- We offer a complete study of the environmental assessments of a mineral waste and the used methodology.
- The described methodology can be reemployed for other mineral wastes as well as household hazardous wastes.
- The work is useful for a lot of countries where natural resources are scare.

ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form 13 February 2014
Accepted 17 February 2014
Available online 24 March 2014

Keywords:
Industrial minerals
Leaching
Mineral processing
Recycling
Pollution

ABSTRACT

Foundry industry produces a huge quantity of foundry sand; its management has become an environmental, economic and social imperative since it is now considered as dangerous waste. Besides, non-renewable natural resources conservation drives investigations on potential recycling of industrial by-products. A source of 150,000 tons of foundry sand stock near a secondary road under rehabilitation led to an investigation on the feasibility recycling of this waste within sub-base layer. The new road material has to satisfy geotechnical functions and environmental prescriptions, avoiding any important leaching of polluting elements.

This paper presents the chemical analysis of this by-product, the formulation of a sub-grade material and its leaching behavior assessed by experimental site monitoring.

The results show that this foundry sand, treated by 5.5% of hydraulic binder, displays acceptable mechanical performances and do n't shows environmental impacts. This investigation demonstrates that this foundry sand can be used in road layers as road materials.

1. Introduction

Today society produces a huge volume of industrial wastes whereas their continuous increase requires strategies to recover and recycle these materials since their disposal by landfilling is limited by a decreasing availability of space, and increasing cost of disposal. On the other hand, the construction of roads requires a large volume of aggregates, driving a significant and unending demand. In industrial countries around the world there is an increased interest for recycling and therefore for resources saving [1,2]. Since virgin materials become scarce, roads can represent a viable outlet to recycle mineral by-products [3–5]. Previous studies show the possibility of reusing materials in road construction i.e. crushed concrete [6–8], roofing shingle scrap [9,10], foundry sand (FS) [9–13], nonferrous slag [9,10], steel slag [8–10], blast-furnace slag [7,9,10], coal bottom ash [7,9,10,14], coal boiler slag [10], crushed glass [8–10], scrap rubber [8], scrap tires [9,10], municipal solid waste incinerator ash [8,9,14], reclaimed asphalt pavement [8–10,15] and waste plastic granules or fibres [8]. These secondary materials have been used as aggregates or mineral fillers in major pavement construction applications like asphalt concrete, Portland

* Corresponding author. Tel.: +33 3 85 86 67 84; fax: +33 3 85 86 67 79.
E-mail addresses: Oumaya.marzouk@developpement-durable.gouv.fr (O. Yazoghli-Marzouk), Nelly.vulcano-greullet@developpement-durable.gouv.fr (N. Vulcano-greullet), Laurent.cantegrit@developpement-durable.gouv.fr (L. Cantegrit), Laurent.friteyre@developpement-durable.gouv.fr (L. Friteyre), agnes.jullien@isfttar.fr (A. Jullien).
[1] Nelly Vulcano-Greullet moved to DREAL, SRPN/EMA, France.
[2] Tel.: +33 3 85 86 67 84.
[3] Tel.: +33 4 74 27 53 97.
[4] Tel.: +33 4 73 42 10 55.
[5] Tel.: +33 2 40 84 59 38.

http://dx.doi.org/10.1016/j.conbuildmat.2014.02.055
0950-0618/

cement concrete, stabilized base, granular base, flowable fill and embankments/backfill [5,6,10].

Foundry sand consists primarily of clean, uniformly sized, high-quality silica sand or lake sand that is bonded to form moulds and cores for ferrous (iron and steel) and nonferrous (copper, aluminium, brass) metal castings [16] due to its thermal conductivity [17,18]. In foundry, the sand is reused several times by regeneration. When it can no longer be reused in foundry process, it is removed from the foundry and qualified as waste foundry sand (WFS). Then it is tested, analysed and stored and starts another life. Hence according to the above framework this paper examines a stock of foundry sand (FS) and an application of in situ recycling and field tests to characterize release to environment during its life cycle.

2. Background

Fig. 1 shows the FS life cycle, that is, how foundry sand is produced, regenerated in foundry plant and stored. In this paper we study another scenario besides foundry use, which needs to investigate other applications such as road construction. An overview of the literature devoted to road applications of FS is hence firstly analysed below.

2.1. Literature overview of FS use in roads

Up to now, in France, waste foundry sand (WFS) has been used in embankments, in industrial roadbed, or in trenches in the framework of the technical guide for embankments and sub-base layer [5,6,9,10,13,19–24]. However, its use is forbidden in quarry and excavation embankments when interactions with water are possible. The foundry sand can also be used in sub-base layers if the water phenol content obtained from leaching tests is lower than 5 mg/kg of dried sand. Genet et al. [22] tested different mix composition, that is, substitution of 15% of total sand in untreated coarse gravel, the same ratio in treated sand with hydraulic binder and a

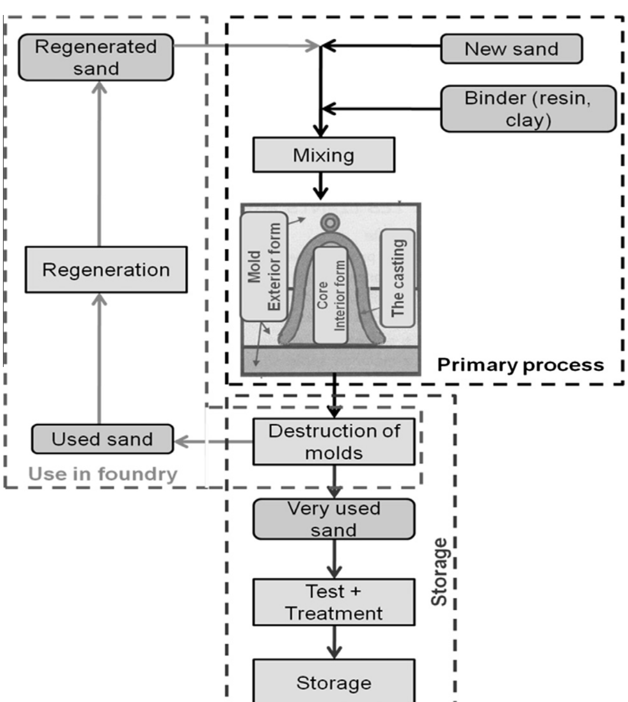

Fig. 1. Production process of foundry sand: primary use, reuse in foundry process and storage.

ratio of 20% in treated coarse gravel with hydraulic binder. He noted that organic material content can have an inhibiting effect on hydraulic binder reactivity. Overall the quality of foundry sand such as its origin, storage conditions, clay content, and sieve analysis is found very important. Significant quality variations will indeed have an impact on the characteristics of the final product. Hence, a laboratory testing program was conducted on foundry sand mixtures to assess their applicability as highway sub-base materials [25]. The mixtures consist of foundry sand, foundry sand treated with 5% of quick lime or 5% of type 1 Portland cement, foundry sand mixed with crushed rock at 55% and 73% with and without cement treatment. The results indicated that an increase in the strength of foundry sand based mixtures can be obtained by a high compaction effort, at dry of optimum, and higher strength can be reached by adding cement or lime and preventing intrusion of excess water in the field. For all the tested specimens, the resistance to winter conditions (freeze–thaw cycles) is better for foundry sand based specimens.

Foundry sands were also recycled in flowable fills [11,26–30]. ACI 229R [26] reports that foundry sand with up to 20% fines produced successful flowable fill mixtures (generally the mixture consist of cement, water fly ash and aggregates). Even foundry sand with organic binders may be suitable.

Furthermore foundry sand was used as well as fine aggregate in hot mix asphalt pavements [27,31–33]. In these investigations the feasibility for use of waste sands as a fine aggregate in asphalt concrete has been examined by replacing various portions of conventional aggregates with waste foundry sand from ferrous foundries. The results showed that the replacing proportion of 15% give satisfactory performances for hot mix pavement. When the proportion is higher than 15%, the asphalt mix become more sensitive to moist damage (stripping, loss of aggregate, pavement deterioration), the use of antistripping additives is thus recommended.

Foundry sands from nonferrous foundries can contain high concentrations of heavy metals so that their use in pavement is not acceptable. In all cases, the measurement of clay content is very important as it determinant for aggregate-binder adhesion [34]. Another investigation [35] shows that foundry sand can also be used in foamed bitumen bound mixtures for road pavements by cold recycling.

In this work, the natural sand was completely replaced by foundry sand. The mechanical tests (indirect tensile strength, stiffness modulus and permanent deformation tests) performed on the foamed bitumen bound mixtures obtained, at dry and wet conditions, show that the optimal binder content is 3%, the results regarding indirect tensile test and stiffness modulus satisfy the standards for road materials.

One of the obstacles to the use of foundry sand in road materials concerns environmental impacts and few information is available in this field. In their research, Guney et al. [25] assessed the environmental suitability of the foundry sand-based mixtures by leaching tests, pH and electrical conductivity measurements. The pH increased when cement or lime is used, and the electrical conductivity decrease due to an encapsulation process observed during cement stabilization. The elements analysed in the leachate (nickel, chromium, lead, copper, zinc and cadmium) showed that the concentration of the different metals decreases gradually. The groundwater will thus not become contaminated with metallic compounds since the measured concentration were lower than US EPA (Environmental Protection Agency) maximum concentration limits. Other studies [36,37] showed that the concentrations of zinc, lead, chromium and iron leaching from foundry sand may exceed the US EPA limits but remain acceptable when the difference is only 10%.

Ideraldo et al. [34] studied the feasibility of using foundry sand in hot mix asphalt for flexible pavements. They used waste foundry