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Evaluation of controlled low strength materials containing industrial by-products

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Abstract

A controlled low strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill. It is also known as a flowable fill which is usually a mixture of fine aggregates, small amount of cement, fly ash, and water. To be classified as a CLSM, the mixture must have a compressive strength between 345 and 8400 kPa. This paper evaluates the potential use of cement by-pass dust, incinerator ash and copper slag as a CLSM. Mixtures were designed to produce a CLSM, with a low compressive strength (less than 1034 kPa), that can be excavated without using any mechanical equipment. Slump, unit weight and unconfined compressive strength tests were conducted on various mixtures. Cubical and cylindrical specimens were prepared and cured at room temperature and in sealed plastic bags. Results indicate that with a good mix design it is possible to produce a CLSM with good mechanical properties to meet design requirements. Mixing these materials with cement and sand produced better results than using them alone due to their low pozzolanic activity. Curing method and period can have considerable effects on the strength of a CLSM.

Keywords: Controlled low strength material; Flowable fill; Cement by-pass dust; Incinerator ash; Copper slag; Strength; Backfill; Slump

1. Introduction

The proper disposal of waste materials that are produced from various industries is a serious problem in many countries. Generation of industrial waste materials and by-products is increasing as a result of industrialization, and the need for higher amounts of raw materials and fuel to accommodate the rapid increase in the world's population. This obviously causes many environmental problems in the form of waste generation, and raises the potential to contaminate water, air and soil resources. The safe disposal of waste is costly, and there is a lack of disposal sites that are suitably designed to handle such materials without causing detrimental effects on the environment. Therefore, in recent years, research has been directed towards finding alternative methods of utilizing waste materials and industrial by-products, where their harmful effects are minimized or even eliminated. The construction industry is one of the areas where the safe use of waste materials could have a promising future. It was well known, for more than three decades, that the use of industrial by-products such as fly ash (FA), silica fume, pulverized-fuel ash and granulated blast furnace slag as a partial replacement of cement improves the durability of concrete structures and may also enhance the properties of both fresh (e.g. workability, bleeding, etc.) and hardened (e.g. strength) concrete. This is well documented in various codes of practice [1–4].

Another application where such materials can be re-used beneficially as flowable fills or controlled low strength materials (CLSMs). A CLSM is a slurry consisting of a mixture of cement, sand, water and FA. Since sand and cement are the major components of CLSM; replacing the cement and/or natural sand with waste materials is an attractive beneficial reuse option. CLSMs are engineered materials that have a specified compressive strength $\leqslant 8.3$ MPa at 28 days [5]. If future excavation is desired, however, the compressive strength should be $\leqslant 1034$ kPa. CLSMs are self-leveling, liquid-like materials, and they are also self-compacting to 95–100% of the maximum unit

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weight. Benefits of CLSMs include: limited required labor; accelerated construction; ready placement at inaccessible locations; and the ability to be manually re-excavated. Their applications include utility trenches, building excavations, underground storage tanks, abandoned sewers and utility lines, slab jacking, and filling underground mine shafts [6,7].

Research interest in CLSM has significantly increased in recent years. FA and foundry sand have been successfully used in CLSM production [7–15]. Also, Butalia et al. [16] found that the use of flue gas desulfurization (FGD) gypsum as a flowable fill material has comparable properties to normal flowable fills in terms of placeability, compressive strength and excavability. They also observed that FGD gypsum use in flowable fills with additives and admixtures compared favorably with the characteristics of conventional quick-set flowable fills. The potential use of cement kiln dust or cement by-pass dust (CBPD) as a CLSM was studied by Al-Jabri et al. [17] and Pierce et al. [18]. Results from both studies demonstrated that cement kiln dust could be beneficially added to produce very low-strength materials that offer comparable strengths to soils used in conventional fills and many other low-strength applications. Pierce and Blackwell [19] and Siddique and Naik [20] reported that scrap tire rubber, when used as a lightweight aggregate in flowable fills, could be utilized in a substantial number of construction applications such as bridge abutment fills, trench fills, and foundation and support fills. Katz and Kovler [21] investigated the use of industrial by-products for the production of CLSMs. Five different by-products were evaluated: cement kiln dust, dust from asphalt plants, coal FA, coal bottom ash, and quarry waste. Results showed that in most cases a CLSM with good properties could be made with significant amounts of dust (25–50% by weight), especially when the dust has some cementing or pozzolanic potential such as class C FA and cement kiln dust. Recently, the effect of water quality on the strength of flowable fill mixtures was evaluated by Al-Harthy et al. [22]. Water used in the investigation was obtained from four major oil production fields in Oman. Results indicated that the use of non-fresh water produced lower compressive strength in comparison with potable water. However, all water types still generated an acceptable 28-day compressive strength requirement of 350–3500 kPa for flowable fills.

The present paper studies the potential use of CBPD, incinerator ash and copper slag as a CLSM. Mixtures were designed to produce a CLSM with a low compressive strength (less than 1034 kPa) that can be excavated without using any mechanical equipment.

2. Materials

In addition to cement and sand, three types of waste materials were selected for the production of CLSM.

2.1. CBPD or cement kiln dust

This is a by-product of the manufacture of Portland cement. It is generated during the calcination process in the kiln. The composition of CBPD varies depending on its source. This is due to variations in both the raw material and the fabrication process. In this study CBPD was obtained from the Oman Cement Company where approximately 30,000 tons are produced every year. The product comes as a fine powder, which is ready to be used with cement mixtures. CBPD is considered as a waste material, and is currently being disposed of on site without any further reuse.

2.2. Copper slag

This is a by-product material generated in the process of copper manufacturing. Here, the raw materials consist of different metals; during the manufacturing process the copper settles down in the smelter due to its higher density while the remaining materials stay in the upper layer to be later transported to a low temperature water basin for crystallization. The end product is a solid, hard material which is brought into the crusher for further processing. The Copper slag used in this work was obtained from the Oman Mining Company. This company produces an average of 60,000 tons of copper slag per year. Copper slag is currently commercialized as an abrasive material.

2.3. Incinerator ash

This material was obtained from small incinerator units at Sultan Qaboos University. The ash results from the burning of domestic garbage collected from different premises in the University. Both low and high incinerator ash contents were included in the testing program.

2.4. Sand

Sand was purchased from a nearby crusher in Al-Khoudh Area, which is from the same batch used in normal concrete mixtures. The gradation test conducted on the sand showed that it met specifications' requirements.

2.5. Cement

Ordinary Portland cement (OPC) from the Oman Cement Company was used in this project. This is the most widely used cement by the construction industry in Oman.

Table 1 presents the physical properties and chemical composition of the Portland cement and the various waste materials used in this study. The high alkali content (K_2O and Na_2O) of CBPD and incinerator ash can cause alkali-silica reactions (ASR) in concrete. However, these are not expected to cause ASR in CLSM as they are both added in