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Recycling of scale and steel chips waste as a partial replacement of sand in concrete

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ABSTRACT

Modification of concrete properties by the addition of appropriate materials is a popular field of concrete research. This study is focusing on the use of selected waste of iron and steel industry (steel chips and scale) as a partial replacement for sand in the production of concrete. In this research study, concretes were made with steel chips scale (*ScC*) and (*SchC*) as substitution for raw sand. Sand was replaced by these waste in different proportions (25%, 50%, 75%, and 100%) by weight of sand.

The aim of this study is to investigate the compressive strength and absorption properties for gamma radiation of concrete with steel chips and scale waste as a partial replacement for sand. The tests results obtained from concretes produced with scale and steel chips were compared with those in conventional concrete (*CC-0*).

The experimental results indicate that, the addition of these waste to concrete enhances the absorption of gamma radiation without impairing other technical features of the investigated concrete. The data shows, that the concrete mixed with steel chips have better strength than conventional concrete, while in the case of concrete mixed with scale in excess of 25%, the strength become deteriorated. The linear attenuation coefficient of gamma radiation of concrete with a mixture of scale and steel chips with 75% and 100% was very good while the rest have good and satisfying radiation properties. Consequently, concrete prepared from the iron and steel industry solid waste containing steel chips and scale could be preferred for buildings as shielding concretes against gamma radiation. In this research the thickness of the concrete shield which can be used instead of the conventional concrete was also calculated.

1. Introduction

In the last few decades there has been rapid increase in the waste materials and by-products production due to the exponential growth rate of population, development of industry and technology and the growth of consumerism [3]. Iron and steel industry represents one of the major constituents of industrial solid waste. The principal sources of this type of solid waste are likely to include iron and steel manufacturing plants, as well as small and medium sized workshops [12]. Scale, granulated slag, and steel chips are an industrial waste in the iron and steel industry and causes a nuisance both to the health and environment when not properly disposed.

The basic strategies to decrease solid waste disposal problems have been focused at the reduction of waste production and recovery of usable materials from waste as raw materials as well as recycling of waste as raw materials whenever possible [16]. Recycling is a logical option for materials not suitable for composting or incineration. Iron and steel waste, are the most common of these materials. With increasing environmental pressure to reduce waste and pollution and to recycle as much as possible, the concrete industry has begun adopting a number of methods to achieve these goals [30]. The use of industrial solid waste as a partial replacement of raw materials in construction activities not only saves landfill space but also reduces the demand for extraction of natural raw materials [29,34].

Wider usage of radiation techniques creates the necessity to protect people against both electromagnetic and neutron radiation [13]. In the building industry it is used for:

– the construction of shields protecting personnel who work in laboratories where radiation is used;
– the construction of hermetic radiation resistant coating of atomic piles;
– the construction of burial grounds for nuclear waste deposition [1].

The most convenient and expedient way in which the aforementioned constructions can be realized is through the introduction of special kinds of concrete. This type of concrete which protects against gamma radiation must be characterized by high attenuation of this radiation. In order to increase the absorptive properties of concrete such component as heavy aggregates barite,

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heavy sand and many others need to be added. Modification of concrete properties by the addition of appropriate materials is a popular field of concrete research. However, iron and steel industry waste as scale, and steel chips have not been evaluated for this purpose up to now. The main goal of this study was to investigate the impact of scale and steel chips waste from iron and steel industry on the compressive strength and absorption properties for gamma radiation of concrete. Scale, and steel chips are taken into consideration specifically because their high density allows them to be used as heavy aggregates.

2. Literature review

Compressive strength of concrete has been accepted as the most important mechanical property of structural concrete. The relationship between concrete composition and compressive strength has long been a matter of interest for researchers [6]. Frondistou-Yannas evaluated and compared the mechanical properties of conventional concrete and concrete mixes made with the pieces of concrete from demolition waste in the place of natural coarse aggregate material [11]. He found out that recycled concrete best matches the mechanical behavior of conventional concrete when the recycled concrete is enriched in gravel at the expense of mortar. The recycled aggregate concrete has a compressive strength of at least 76% and modulus of elasticity from 60% to 100% of the control mix.

Test results by Rai et al. [28] explored the possibility of using metallurgic slags (granulated and air-cooled) in making blended slag cement with conventional Portland cement. The results, which indicated that slag could be used with slight modifications as non-structural concrete, provided a direction for profitable plans for making blended slag cements. Demirboga and Gul [8] used blast furnace slag aggregate (BFSA) to produce high-strength concretes (HSC). Their results showed that the compressive strength of BFSA concrete was approximately 60–80% higher than that of traditional concretes. These concretes also had low absorption and high splitting tensile strength values.

In recent studies, various types of materials have been investigated as sand or aggregates replacement. Batayneh et al. [5] used demolished concrete, glass, and plastic in concrete production, and concluded that the main findings of this investigation revealed that the three types of waste materials could be reused successfully as partial substitutes for sand or coarse aggregates in concrete mixtures.

Ismail and Al-Hashmi [12] investigated the impact of waste iron on the properties of concrete as determined by an extensive series of tests. Their results indicated that the concrete mixes made with waste iron had higher compressive strengths and flexural strengths than the conventional concrete mixes.

Al-Jabri et al. [3] reported an experimental program to investigate the effect of using copper slag as a replacement of sand on the properties of high performance concrete (HPC). The results indicate that there is a slight increase in the HPC density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increase in copper slag percentage. Addition of up to 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which is almost 16% lower than the strength of the control mix.

Research carried out by Qasrawi et al. [27] on the use of low CaO unprocessed steel slag in concrete mixes showed that depending on the grade of concrete, the compressive strength is improved when steel slag is used for low sand replacement ratios (up to 30%). When optimum values are used, the 28-day tensile strength of concrete is improved by 1.4–2.4 times and the compressive strength is improved by 1.1–1.3 times depending on the replacement ratio and the grade of concrete. The best results are obtained for replacement ratios of 30–50% for tensile strength and 15–30% for compressive strength.

Properties of concrete containing a high volume of tire–rubber particles as mineral aggregates replacement were investigated by Khaloo et al. [14]. The results of a uniaxial compressive strain control test conducted on hardened concrete specimens indicate large reductions in the strength and tangential modulus of elasticity. The maximum toughness index, indicating the post failure strength of concrete, occurs in concretes with 25% rubber content. The results showed also that the fresh rubberized concrete mixtures with increasing rubber concentrations present lower unit weights compared to plain concrete. Workability of rubberized concrete with coarse rubber particles is reduced with increasing rubber concentration; however, rubberized concrete with fine rubber particles exhibits an acceptable workability with respect to plain concrete.

Özkan et al. [19] carried out a study into the strength properties of concrete incorporating coal bottom ash (CBA) and granulated blast furnace slag (GBFS), and concluded that replacement of (GBFS) and (CBA) as fine aggregate in concrete generally decreases the compressive strength.

With increasing use of gamma-ray active isotopes in industry, medicine and agriculture, it has now become necessary to study shielding properties in various materials of technological and biological importance. There is away a need to develop material, which can be used under harsh conditions of radiation exposure and can act as shielding materials [15,32].

A number of experimental and theoretical works have been performed on radiation shielding, which has large different application areas with different materials (e.g. igeneous rock, semiconductor, colemanite, etc.) [18,33,35,36,2,4,17].

In general, various materials have been used for the radiation shielding in different applications. For example, polyethylene, glasses, epoxy resin, colemanite, lead and concentrate have been used for neutron and gamma shield, and also, lead, Lipowitz alloy and Cu–Ag polymer were used for electrons shield [26]. In order to match shielding properties to the concrete based composites, boron, lead or their compounds have been used [7,9].

Photon attenuation coefficient is an important parameter for characterizing the penetration and diffusion of X-and γ-rays in the multi-element materials. The scattering and absorption of gamma radiations are related to density and effective atomic numbers of material; knowledge of the mass attenuation coefficients is of prime importance. However, the linear (μ, cm^{-1}) or mass attenuation (μ/ρ ($cm^2\ g^{-1}$)) coefficient, which are defined as the probability of all possible interactions between γ-rays and atomic nuclei, has been described to investigate the radiation shielding properties of any shielding materials. These attenuation coefficients depend on the incident photon energy and the chemical composition of the absorbing materials' parameters such as their types, thickness and densities. The accurate values of mass attenuation coefficients (μ/ρ) of γ-rays in several materials are of great importance for industrial, biological, agricultural and medical studies. A number of related parameters can be derived from mass attenuation coefficient such as mass energy-absorption coefficient, the total interactions' cross-section, the molar extinction coefficient, the effective atomic number and the electron density [31].

Much research has been conducted on the attenuation coefficient of concretes with various materials. Demir and Keles [7] measured radiation transmission of concrete produced by using borogypsum and colemanite concentrator waste for 59.54 and 80.99 keV gamma rays and investigated whether is useful to add