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Use of ferrous metallurgy waste in concrete production

Khumar Safarli
Department of Technologies of Chemical and Inorganic Substances, Azerbaijan State Oil and Industry University, Azerbaijan

Abstract
The article studies the possibilities of reusing various wastes of the ferrous metallurgy industry (metal scrap, steel shavings, blast furnace slag, etc.) in the concrete production process and its effect on both the physical and mechanical properties of the materials. During the study, the technological scheme of concrete production, as well as the principles of partial replacement of raw materials with cement and aggregates, and the ecological and economic efficiency of this process were analyzed. As a result of the conducted studies, it was determined that the use of granulated blast furnace slag as a cement substitute enhances the resistance of concrete to sulfates and also reduces the heat of hydration. The addition of metal shavings and cutting lathe waste significantly increases the tensile and bending strength of concrete, creating a fiber concrete effect. However, factors such as the volume expansion process caused by the influence of free CaO and MgO and the risk of corrosion of metal particles reveal the need for laboratory experiments and tests. The article also analyzed the import and export statistics of ferrous metal waste in our country in 2021-2022, and assessed the prospects for integrating these wastes into the local construction industry in terms of reducing CO_2 emissions and saving natural resources.

Keywords: Concrete production, metal shavings, environmental sustainability, compressive strength, blast furnace slag

Introduction

In their study, Breesem *et al*. noted that scrap iron is a waste product obtained from metal processing processes as small pieces of iron that appear as fine powder [3]. In their study, they used scrap iron to determine its suitability as a fine aggregate in concrete production. Replacing all or part of the fine aggregate with scrap iron results in significant environmental benefits. The percentages of replacement of fine aggregate with DY (Iron Sawdust) are 0%, 10%, 20%, 30% and 40%. The water-cement ratio adopted in this study is 0.58. Experimental studies conducted in the fresh state show that the slump of mixtures containing 10%-40% iron sawdust (DY) varies between 71-76 mm. The results showed that the slump was reduced by up to 16.47% for mixtures with different DY percentages compared to the reference mixture. This reduction was observed in the mixtures with DY content from 20% to 40%. However, the addition of superplasticizer (SP) improved each slump and compaction factor. The compressive strength of the mixtures with 10%-40% content was in the range of (28.21-40.44) MPa at 28 days. The flexural strength was in the range of (4.51-6.51) MPa at 28 days. According to the results of their study, the addition of DY reduced the 28-day compressive and flexural strengths by 38.51% and 44.32%, respectively. The significance of the study stems from the attempt to reuse waste iron scrap as fine aggregate to save environmental resources and contribute to a sustainable concrete industry.

Johnny Alora and colleagues investigated the use of waste in concrete production in their study [1]. An alternative solution is to recycle these wastes resulting from the construction or demolition of concrete elements of structures and use them as coarse aggregates in concrete production. On the other hand, the metalworking industry, with production sources being industrial enterprises and production workshops for small and medium-sized enterprises, uses iron and steel, which are the main components of industrial waste, as the primary input, and the solution to this problem is to use the wastes as fine aggregates in concrete production due to some of their properties. These solutions conserve natural resources and promote their sustainability. Their research work focuses on the use of structural concrete and steel wastes to reduce the amount of waste generated and proposes to add them to concrete. The results show that the addition of steel sawdust to concrete leads to a decrease in shrinkage, an increase in unit weight, and helps to improve the compressive strength, cylinder splitting tensile and bending resistance.

Concrete aggregates are subject to requirements that take into account their impact on the concrete's properties. In addition to grain size, the most significant factors affecting aggregate performance are the aggregate's strength and surface finish. A distinction is made between ordinary aggregate, which contains grains of varying sizes, and graded aggregate.

Material and Methods

During the study, the possibilities of using ferrous metallurgy waste in the concrete production process were analyzed based on the analysis of modern scientific and statistical materials, as well as existing technological methodologies. As a methodological approach, the principle of including metal shavings as fine aggregate in the composition of concrete, along with the principle of using industrial slag as a cement substitute, was taken as a basis. The results of physical and mechanical experiments were analyzed in a comparative manner. Also, the process of immobilization of waste in concrete and its chemical activity were evaluated based on theoretical methods, and environmental risks were analyzed.

Result

Concrete is an artificial stone material obtained by the hardening of a thoroughly mixed and compacted mixture of a binder and water, fine and coarse aggregate, taken in specific proportions. Before hardening, this mixture is called a concrete mix [2]. The properties of concrete are primarily determined by the quality of the initial raw materials: cement, quartz sand, crushed stone, and additives. Cement and water are the active components of concrete; as a result of chemical reactions between them, cement stone is formed, which binds the grains of fine and coarse aggregate into a single monolith.

Aggregates account for over 80% of concrete's volume. Their role in concrete is to reduce binder consumption, impart properties such as low shrinkage, reduced instantaneous deformation under loading, reduced irreversible deformation—creep—under long-term loading, reduced permeability, and increased durability.

The most important property of a concrete mix is its workability, or formability—that is, the mix's ability to flow under external forces and assume a given shape while maintaining its integrity and homogeneity. Workability is determined by the flowability and stiffness of the concrete mix, as well as its cone flow. A characteristic feature of concrete mix is its constantly changing properties from the beginning of its preparation until hardening. This is due to the complex physical and chemical processes occurring within the concrete mix and as it hardens. Due to the interaction forces between dispersed particles of the solid phase and water, a complex multicomponent system—the concrete mix—becomes coherent and can be considered a single physical body with specific physical and mechanical properties. The following technological factors have the primary influence on these properties: the quantity and quality of the cement paste, the ratio of cement to water volumes, the dispersion of aggregates, the additives used, the effectiveness of which depends on their chemical composition and dosage, etc. To regulate the properties of the concrete mixture and save cement, various additives are used in concrete technology: chemical, mineral, and organomineral. The use of chemical additives is one of the most universal, accessible, and flexible methods of controlling concrete technology and regulating its basic properties.

Durability is defined as the maximum service life of buildings, structures, components, and materials, during which they retain their required performance characteristics despite changes occurring within them and are capable of performing their intended functions. The durability of concrete and other products is linked to their composition, structure, and condition. Therefore, structural materials science, which reveals the regular relationships between properties and composition, structure, and condition, serves as the scientific basis for addressing durability issues.

There are various stages in the production of concrete. If we describe it schematically, it includes both energy and material sources.

This flow chart represents the general material and energy flows associated with the various stages of production in concrete production. The processes considered include the acquisition and preparation of raw materials, cement production, the use of transportation if necessary, the use of fly ash and the production of concrete using these components.

The advantages of using ferrous metallurgy waste in concrete production include the following:

- Reduction of the environmental burden due to the reuse of waste.
- Reduction of production costs due to the partial replacement of cement.
- Increase in the durability and mechanical properties of concrete.
- However, there are also certain risks. These include the following.
- If free CaO and MgO remain in the slag, the volume of the concrete may subsequently expand, which increases the risk of cracking.
- There is a possibility of corrosion of metal particles, which can be observed especially in concrete used outdoors.
- Additional laboratory tests are required for standard mix design.

In their research, Alikca Szymanska *et al*. analyzed the possibilities of managing and neutralizing industrial and municipal waste in concrete production, recycling and molding processes [7]. These possibilities are related to the immobilization of pollutants by creating durable systems using hydraulic binders. This can be achieved by converting soluble compounds into insoluble forms by precipitation of salts, oxides and toxic metals into sparingly soluble hydroxides, sulfides or phosphates. The strength of this material has been determined based on accepted standards and potential environmental risks associated with its production have been identified. Concrete it can exhibit varying levels of radioactivity. However, appropriate modification of concrete allows for the effective storage of hazardous radioactive waste.

Foundry slag obtained by induction is a waste from the ferrous metallurgy industry. Due to its large production volumes and the basic materials used, adding this residue to concrete can be a very interesting solution to convert it into a by-product. The aim of the study by Cesar Cardoso and colleagues is to assess the possibilities of effectively incorporating this slag into concrete mixtures as a substitute for fine aggregates [4]. The properties of fresh and hardened concrete were experimentally studied.

Ferrous metallurgical waste mainly includes industrial slags (blast furnace slags, steelmaking slags) and metal scraps and chips generated in the iron and steel production process. After special processing, these wastes are used as a mineral additive or aggregate (gravel-sand substitute) that replaces part of the cement in concrete production [8].

We can include the following areas of its use.

a. As a cement substitute (mineral additive) [5]

- Granulated Blast Furnace Slag (GGBS) is ground into powder and mixed with cement.
- Regarding its main effect, we can note that it reduces the hydration heat, increases the resistance of concrete to sulfates and chloride ions, and increases long-term strength.
- Regarding the mixing ratio, we can note that 20–70% of cement can be replaced with GGBS (according to regulations).

b. As an aggregate (replacement of gravel or sand) (Shi C. and Qian J., 2000)

- Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slags of steel plants can be used as coarse and fine aggregates of concrete after being brought to a suitable grain size and washed.
- When the added amount is large (e.g. >50%), the workability of concrete may be difficult, but the density and compressive strength increase.

c. Metal scraps and sawdust

- When iron and steel shavings (lathe waste, metal shavings) are added to the mix, the tensile and flexural strength of the concrete increases.
- These types of additives act like fiber reinforced concrete, limiting the development of cracks.
- Artificial metal shavings and industrial waste have been used as additives in reinforced concrete elements. Studies have shown that such an addition significantly increases the flexural strength and durability of concrete: in some samples, the maximum load-bearing capacity was even 1.75 times higher than that of normal concrete.

d. Metal-sawdust and turning waste [6]

- When metal-sawdust and turning waste are added to the concrete, its weight, density and mechanical properties improve, slippage is reduced, and overall strength is increased.
- Such materials can also be used in ferrocement-type structures. This method is a typical technique consisting of a combination of cement and iron mesh.

e. Addition of metal-waste to concrete mortar

- As the amount of metal-sawdust increases, the density of the concrete increases, but high levels of addition (-40% and above) can make workability difficult.
- Metal particles can increase the resistance to harmful concrete tensile stress, and at the same time, when used in conjunction with pozzolanic additives, the hydration process and structural quality can be improved.

f. Reuse of slag types (BOF, EAF)

- Blast furnace slag (BFS) is already widely used as a cement substitute in many countries. In Europe, the recycling rate of this material is around 94–100%.
- Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slags are used as cutting aggregates or binders in concrete production, but sometimes require appropriate pre-treatment due to volumetric expansion and durability issues.

Summarizing what we have mentioned, we can conclude that the forms of use and their effectiveness vary by waste type (Table 1).

Table 1: Use form and efficiency by waste type

Waste Type	Usage Form	Effects and Benefits
Blast furnace slag	Cement Substitute	Increases durability and friction
Metal turnings	Concrete Admixture	Improves flexural strength
Lathe waste	Aggregate or Admixture	Increases density and strength
Metal particles + pozzolan	Aggregate Substitute + Binder	Improves hydration and structural quality
Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slags	Aggregate and Binder Additives	Can be used with hardness, durability is observed

In the initial stage, the raw materials required for our research, such as kaolinite, iron ore, bauxite, laterite, clay, limestone and other similar inorganic materials, are extracted through mining operations [7]. The second stage of our research involves selecting the correct dosage of different raw materials along with their different characteristics. In the next stage, they are fed into the heating chamber. In the final stage, the cooled clinker is removed from the cooling tanks and finally transferred to the mills. This process is illustrated in the following figure (Figure).

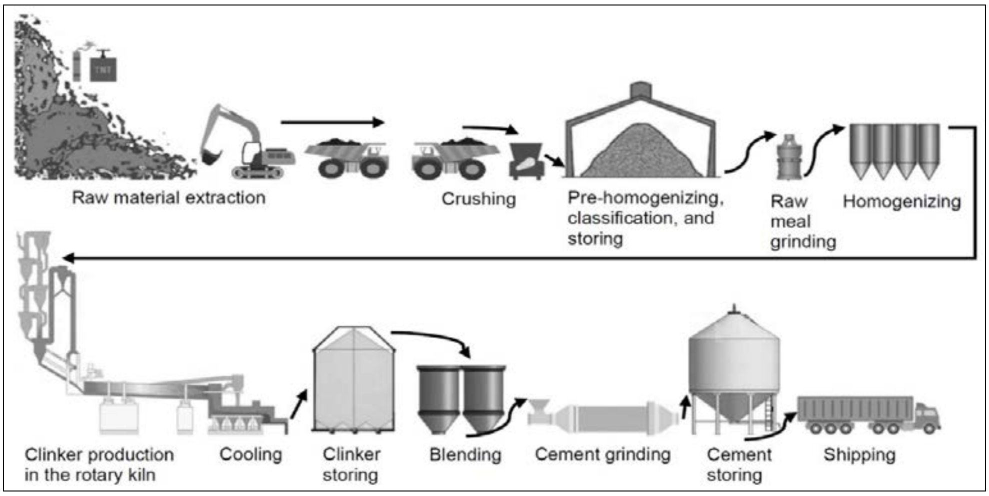

Fig 1: Cement production [9]

An analysis of the obtained results is carried out, during which the compliance of the concrete mix with a certain grade in terms of workability and average density is determined; an assessment is made of the segregation indicators and the retention of the properties of the concrete mix over time, as well as the volume of air entrapped in the concrete mix.

If we look at the statistics on ferrous metal waste in Azerbaijan in 2021 and 2022, which reflect only the amount of foreign trade in ferrous metal waste, the volume of "iron and steel waste" exported by Azerbaijan in 2022 was approximately 2,164,360 kg and its value was 646,020 USD, while 1 year earlier, in 2021, the volume of this waste imported was 1,924,380 kg and its value was 718,420 USD [8].

Conclusion

As a result of the conducted research, it was determined that the inclusion of ferrous metallurgy waste in the composition of concrete, in addition to saving cement and natural aggregates, significantly increases the mechanical durability and environmental sustainability of the material. Recycling of this type of waste generated in our country in this area creates high prospects both in terms of neutralizing industrial waste and further reducing costs in the construction sector.

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