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Acid resistance, sulphate resistance and strength properties of concrete containing ferrochrome ash (FA) and lime

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HIGHLIGHTS

- FA is a waste material of ferroalloy industry.
- Utilization of FA with lime as a substitute of cement is explored in this study.
- Use of FA and lime has positive impact on strength and durability of concrete.
- Optimum substitution of FA is 40% along with 7% lime, replacing 47% of OPC.

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ABSTRACT

Ferrochrome ash (FA) is a by-product of ferroalloy industry. The present study assesses the potential of FA along with lime as a partial substitute material of cement in concrete production. For the purpose, various properties such as workability, fresh density, compressive strength, flexural strength, bond strength, acid resistance, sulphate resistance and sorptivity were investigated for concrete containing FA, varying from 10 to 40%, at an interval of 10% along with 7% lime. Results of investigation revealed that on inclusion of FA and lime the properties of concrete improved. At 47% replacement of ordinary Portland cement (OPC), 40% by FA and 7% by lime, the properties of normal concrete or even better achieved at all ages. Results of destructive tests were well compared with non-destructive tests. Microstructure analysis (condition of gel and degree of hydration) confirmed the results. Results of investigation established the technical acceptability of FA with lime as a supplementary cementitious material.

1. Introduction

Cement concrete is most consumed material next to water in the earth. Cement concrete, because of its economy, ability to be cast to any shape, ability to be fabricated and durability has become popular over the years. Demand of cement concrete will continue far into the future. Cement is the principal and costlier among the ingredients of concrete. Cement manufacture consumes a lot of the oil resources in order to generate the necessary energy for its production. Further, it is a source of greenhouse gas emission. Nearly 130 kg of fuel and 110 KW h of electricity required for production of each tonne of OPC, which emits around 0.9 tonne of CO_2. About 6% of man-made carbon emission is due to production of OPC.

As on date the annual production of OPC is around 3.6 billion metric tonnes and by 2030, it may rise up to 5 billion metric tonnes. The demand of cement will continue to increase in future necessitating the use of alternative cementitious materials. Hence there is an urgent need to find and supply alternative low cost energy saving substitutes of cement by exploring the possibilities of utilization of industrial by-products and waste materials. Industrial waste materials have been accepted as raw materials of concrete. Review of literature revealed that concretes made with industrial by-products and waste materials possess better properties in comparison to conventional concrete. Use of hazardous waste and inorganic industrial waste in concrete production will leads to sustainable concrete technology and green environment.

FA is the dust collected as a waste material from gas cleaning plant of ferrochrome industry. The gas emitted from Ferro – alloy smelting furnaces contain particles of dust, dirt and incompletely combustion wood and/or coal and coke. This gas contains harmful sulphurous, toxic metal oxide vapours, carbon monoxide and other organic gases. Gas cleaning plant cleans above gases and during

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this process of cleaning huge quantity of ash is collected in gas cleaning plant which is named as ferrochrome ash (FA) in this study. FA is dumped without any pollution prevention, control or remediation measures. FA has the potential to pollute water resources. If such type of waste material can be utilised as partial replacement of cement in concrete mixtures without sacrificing or even improving strength and durability properties, there is possibility of tremendous economic as well as ecological gain. The contents of ferrochrome ash satisfy the requirements of slag and can be used as a pozzolanic material along with lime for replacement of cement. Possibility of utilization of this waste material in concrete making as partial replacement of ordinary Portland cement is explored in this research.

Lime is being used as a binding material all over the world since ancient age. Lime stone powder as a filler material in concrete is a common practice in many countries. Lime is cheaply and sufficiently available in nature. Lime stone dust produced due to massive quarry operations is creating manifold environmental problems. The disposal and utilization of lime dust is also one of the subjects of current interest today. Utilization of lime dust in small quantity along with FA is explored in this study. It was investigated for use of lime in small quantity varying from 5 to 10% on blended cement based concrete and found that 7% of lime substitution shows better performance. So use of lime is considered as 7% only in OPC blended with FA. The concept of study is based on pozzolanic reaction.

$$\textit{Pozzolanic material} + \textit{calcium hydroxide} + \textit{Water} = C - S - H\ \textit{gel}$$

The volume of carbon dioxide emitted by the cement industry is nearly 900 kg for every 1000 kg of cement produced [1]. Use of supplementary cementitious materials (SCMs) in cement production reduces emissions of carbon dioxide. SCMs include ground lime stone, natural and artificial mineral pozzolanic compounds. Lime stone powder is used as a filler material to replace Portland cement. The fineness of cement affects the early age strength significantly due to acceleration in hydration. Blending finer cement with a coarser fly ash affects the early age strength positively. The volumetric substitution of fly ash up to 35% is found feasible for producing sustainable concrete [2]. Because of easier grind ability of lime stone than clinker, at the same Blaine fineness, the clinker is concentrated in the coarser fractions and lime stone powder in the finer. The strength of Portland limestone cement (PLC), containing lime stone powder is found better than that of Portland cement. Sulphate resistance of concrete made of PLC improved due to lime stone powder. Limestone powder improves particle packing, enhances hydration, reduces bleeding and increases workability in PLC when compared to OPC. It reduces cost and CO_2 emissions. PLC containing limestone up to 20% reduces energy requirement and carbon emission up to 10% [3]. The setting time of concrete containing lime stone powder up to 30%, made with a constant water-to-cement ratio of 0.45, was faster than that of control concrete. The compressive strength decreased with the increasing content of lime stone powder. The trend of diffusion of chloride ions in concrete was found to increase with age, enlargement of replacement and fineness levels [4]. The strength of paste increases with increasing time of hydration. As hydration proceeds more hydrated calcium silicate C-S-H (I) and/or C-S-H (II), are framed and deposited in the open pore system of the hydrated paste leading to a continuous increase in compressive strength of hardened paste. The strength of lime-rich mixes (1.70 and 2.0 CaO/SiO_2 molar ratio) is slightly increased at the later ages of hydration due to the process of carbonation of free lime that retards the continuous formation of C-S-H as representing the main binding centers of the hardened paste [5].

The early age compressive strength of concrete containing fly ash improved due to inclusion of lime and silica fume. The air permeability decreased in comparison to normal concrete. The inclusion of silica fume and hydrated lime impressed the sorptivity and lowered the total porosity [6]. Inclusion of 10% lime stone sulphate resistant cement increases the rate of hydration up to the age of 90 days. Liberated free $Ca(OH)_2$ reduced to minimum due to addition of 10% of silica fume. Cement paste containing 5% of both lime stone and silica fume exhibited good strength properties and lowered porosity at all curing periods [7]. High lime fly ash is a self-cementing pozzolanic material. Water demand and air content of concrete is greatly affected by the fineness and carbon content properties of high lime fly ash. Early age compressive strength of high lime fly ash concrete is affected by free lime and the desired strength is obtained at 56 days of curing. Concrete containing 25–35% high lime fly ash achieved best strength properties. The compressive strength gain decreases beyond 35% fly ash content but remains above the designated strength [8]. The compressive strength of mortars containing 25 and 50% of sewage sludge ash (SSA) reduced than control. SSA has a long term positive effect which is related to its pozzolanic activity [9]. The replacement of various industrial wastes such as fly ash, slag, silica fume and marble dust (up to 20%) improved the compressive strength of mortar [10].

Use of waste materials like blast furnace slag, fly ash and silica fume in concrete decreased the permeability of concrete and increases the quality of concrete [11]. Compressive strength of concrete mix containing 25% of natural pozzolan, decreased slightly (less than 5%) after 180 days. However modulus of elasticity increased and chloride ion permeability decreased. Performance in sulphate expansion tests and freeze and thaw tests was not good. The rate of hydration was found slow because natural pozzolan contained less amorphous silica. After 90 and 180 days of curing, best properties were reported [12]. Inclusion of natural pozzolana on partial replacement of Portland cement has positive effect on corrosion. The compressive strength decreased with an increase in pozzolana content [13]. On inclusion of lime and ferrochrome ash the water demand increased, workability and setting time decreased while soundness remained consistent. The early age compressive strength increased significantly on inclusion of lime and ferrochrome ash. Highest increase in properties like compressive strength, modulus of elasticity and splitting tensile strength achieved by concrete mix containing 10% ferrochrome ash and 7% lime. The property values got reduced with an increase in ferrochrome ash content but remained more than control at all ages [14].

In spite of large literatures available on use of lime, natural pozzolana, bottom coal ash, fly ash, sewage sludge ash etc. as substitute material for replacement of cement, very less is known on ferrochrome ash. A little is reported yet on effect of ferrochrome ash on some properties. To establish ferrochrome ash with lime as a substitute of cement, some more investigations on various properties are essential. Its effect on properties like fresh density, flexural strength, bond strength, acid resistance, sulphate resistance, sorptivity etc. is explored in this research. Hence the present investigation is an attempt to bridge the knowledge gap.

2. Material and methods

2.1. Materials

Ordinary Portland cement (43-Grade) conforming to IS: 8112:1989 [15], natural sand (fine aggregate) from local river-bed conforming to grading zone III of IS: 383-1970 [16] and black hard coarse crusher broken granite natural stone aggregates conforming to IS.383-1970 were used. FA was collected from Balasore Alloys Ltd, Balasore, Odisha, India (Fig. 1). The lime used in the experiment was procured from local market (Fig. 2). Properties of cement, aggregates, FA and lime are already reported by authors of present study [14].