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USE OF FERROCHROME ASH AS REPLACEMENT CEMENT CONCRETE PAVEMENTS – A REVIEW

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ABSTRACT
Industrial wastes and by-products have been explored for many years as green construction materials. The use of some industrial wastes and by-products including ground granulated blast furnace slag, silica fume, Red mud and fly ash has already been standardized in several codes of practice as green construction materials. There is a lot of wastes from industries like fly ash, GGBS, and slag-based compounds which can be used as replacement materials for aggregates. Ferrochrome Ash (FA) is a byproduct of gas cleaning plant of Ferrochromium industry and past studies established it as a mineral admixture to cement. Due to its chemical composition, physical nature, and mechanical properties, Ferrochrome ash has recently attracted the researchers' the review article summarizes the physical, chemical, and mechanical characteristics of Ferrochromeash. It is observed from the review of literature that concrete made with industrial by-products and waste materials by partially replacing the ingredients of concrete possess superior properties as compared to conventional concrete in terms of strength, performance and durability. The particle size distribution, the chemical composition, mineralogy, microstructure of binder particles were analysed with advanced analytical techniques such as XRF, PSA, XRD, SEM/EDS. The results of this study not only suggest the effective utilization of ferrochrome ash for the synthesis of a new class of geopolymer binders but also provide a sustainable route for the management of ferrochrome waste currently generated in various countries worldwide. This paper presents an overview of the recent advances of the use of ferrochrome ash in various civil engineering applications such as road construction, and cement and concrete industries.

1. INTRODUCTION

Global annual production of ferrochrome is around 6.5–9.5 million tonnes. It is increasing at the rate of 2.8–3% per year. Accordingly the generation of ferrochrome waste is increasing parallel with the production of ferrochrome and is currently being dumped, polluting the environment without any attention towards prevention, control and remedy. Two such wastes from the Ferro alloy industry are ferrochrome ash (FA) and ferrochrome slag (FS). FS to the tune of 1–1.2 tonnes and FA of 0.02–0.03 tonnes are generated during the production of each tonne of ferrochrome product, Tribikram Mohanty (1). The greenhouse effect can be reduced by partial replacement of cement by some waste product of such as fly ash, ferrochrome ash, silica fume, red mud and GGBS etc. studied the mechanical properties and durability characteristics of concrete enhanced with ferrochrome ash (FCA) as a partial substitution for cement. investigated the performance of Ferrochrome ash (FCA) based concrete and noted that at 47% (40% FCA and 7% lime) replacement of cement produced almost same mechanical properties as ordinary concrete at 28 days of curing and concrete strength has been enhanced for later age, conducted the XRD and petrography studies of 47% (40% FA and 7% lime) replacement of cement and confirmed the results of mechanical and durability properties of their earlier studies, Monalisa Sharma (2). With an objective to use FCA in large scale, research was carried out by the authors to investigate the effect of FCA, used in various % (10-40% at an interval of 10%) with 7% lime on replacement of OPC. X-ray diffraction study of FCA was carried out using Shimat Zu 6100 difractometer with Cu-Kα 1-1.54Å radiation. XRD study that FCA is rich in SiO_2 and Al_2O_3 which indicates that it can act as pozzolanic material, Prasanna (3), Most of the world's ferrochrome is produced in South Africa, Kazakhsthan and India, which have large domestic chromite resources. The avearge chrome content n stainless steel is approximately 18%. Ferrochrome from Southern Africa, known as "charge chrome" and produced from a chromium containing ore with a low carbon content, is most commonly used in stainless. In the reduction of production of ordinary Portland cement, minimization of greenhouse emissions, lowering of energy consumption, management of environmental burden and conserving natural resources utilization of ferrochrome ash in concrete making will be useful, Shrinu Mohanty (14). The cement has been replaced with 10%, 20% and 30% fly ash respectively. The beam is observed with fly ash and ferrochrome ash gives more ductility than of conventional concrete. Hence 30% fly ash and 3% ferrochrome ash as partial replacement of cement has been strongly recommended, Tribikram Mohanty (11), The source mix containing 80% FCA and 20% GGBFS provided the highest

28-day compressive strength of 30.2 MPa under open-air curing conditions which is suitable for general in-situ construction works. It can be seen from that the EE requirement and ECO 2 release to the atmosphere for the FCA- and GGBFS based geopolymer concrete increases with the increase in GGBFS content in the mix. The target compressive strength of all the geopolymer mixes is less in comparison to OPC-based normal concrete except the mix F80G20. In mix F80G20, the compressive strength is 13.5% more than the OPC-based concrete with a simultaneous reduction in carbon emission and embodied energy, Jyotirmoy Mishra (8).

This review would help researchers to identify the research gaps that have to be bridged for the efficient and safe use of FCA in concrete as an Replacement of cement.

Ferrochrome ash

Due to the scarcity of land filling area, utilization of wastes in the construction sector has become an attractive proposition for disposal. Ferrochrome ash (FCA) is a waste material obtained in huge quantity from gas cleaning plant of the ferrochromium industry. The gaseous material emitted from the furnaces of smelting of alloy of iron or Ferro contains many impurities like particles of dust, improperly burned materials like timber. Due to less amount of landfilling areas dumping of industrial waste materials like ferrochrome ash have become a difficult task. A plant manufactured for the cleansing of these harmful gases is liable to process a considerable amount of particles of dust or ash which contains FCA the main constituent. Inclusion of FCA and lime has positive impact on water permeability and ultrasonic pulse velocity. The development in properties of concrete containing FCA and lime is reported significant at early age, comparable at 28 days and appreciable at later age. Ferrochrome ash and gypsum the additional benefits from this includes cost reduction, energy savings, promoting ecological balance and conservation of natural resources etc. Concrete containing ferrochrome ash FCA and gypsum powder GP is an environment friendly material. The wastes from Ferro alloy industries face disposal problems because of the residual chromium content. To date, these wastes are being land filled. The possibility of utilization of Ferrochrome slag as a coarse aggregate replacing natural coarse aggregate and FA with lime as a partial replacement for cement is explored in this research in preparation of low-cost, energy-saving, green concrete. The FCA consisted mostly of very fine and porous particles as compared to comparatively large, irregular-sized GGBFS particles.

Materials

Ordinary Portland Cement (OPC) 43 grades, Ferrochrome ash (FA), Silica fume (SF) and Red mud (RM) which are locally available in Odisha, India are used for this experimental work. Ferrochrome ash and Silica fume are available in powder forms and readily used without any further treatment. Red mud is little bit wet or content moisture when brought from aluminum industry and converted into a powder form after oven drying.

2. LITERATURE REVIEW

Tribikram Mohanty et al (2019)- The present investigation considers the combined influence on strength of concrete using various percentage fly ash and ferrochrome ash as partial replacement of cement. Experiments are carried out to get mechanical properties of ordinary Portland cement by replacement of fly ash by 10%, 20%, 30 % and 3% by ferrochrome ash. Mechanical properties are measured by determining compressive strength, split tensile strength and flexural strength. Since ferrochrome ash and fly-ash are both industrial waste. Thus the results indicated that Fly Ash 30% with 3% Ferrochrome ash may be considered when a strength requirement is more than normal. The increase in compressive strength, Split tensile strength and Flexure strength 39.45%, 49.43%, 33.33% and 2%. The optimum replacement cement use 3% and 2%, the curing period on 7, 28 and 56 days.

Monalisa Sharma et al (2021)- Ferrochrome Ash (FA) is a byproduct of gas cleaning plant of Ferrochromium industry and past studies established it as a mineral admixture to cement. The present study investigates utilization of Ferrochrome ash (FA) without addition of lime, instead supplemented with other industrial waste like Silica fume (SF) and Red mud (RM) as partial replacement of cement. The mechanical properties of the concrete is investigated considering partial replacement of Ordinary Portland Cement (OPC) by 20%, 22%, 25% and 30% with FA and other industrial waste. The observed that the design mix N80R10 and N75S15 are more economical without compromising the strength. Though concrete mix consisting with RM (N80R10) produce better compressive strength at 28 days as compared to the normal concrete (N100C) but provide marginally less flexural strength.

Prasanna K. Acharya et al (2016)- To establish FCA concrete as a structural material, its behaviour on structural concrete has been investigated. This paper investigated the flexural behaviour reinforced concrete (RC) beams containing 40% FCA and 7% lime replacing 47% OPC. The beams were tested under monolithic loading up to failure. The compressive strength of control concrete (CC) and ferrochrome ash concrete (FCAC), containing 40% FCA and 7% lime were tested at the age of 7, 14 and 28 days. The capacity of the beam, its failure and crack pattern were studied. The flexural behaviour of RC beams, containing 40% FCA and 7% lime (replacing 47% OPC) is comparable to that of normal concrete beams. The ultimate load carrying capacity of FCA concrete beams is found 8.33% more than normal concrete beams. Failure of normal concrete and FCA concrete beams occurred in tension side.

Prasanna K. Acharya et al (2016)- The study carried out to evaluate the possibility of utilization of ferrochrome ash (FCA), a waste product from ferroalloys industries for partial replacement of cement in concrete preparation. FCA is used in four different substitution rates such as 10, 20, 30 and 40% along with 7% Lime. Test results revealed that replacement of cement by FCA in

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various % with 7% lime enhanced the 28 days compressive strength 1.5 - 13.5%, flexural strength 4.5 – 9%, bond strength 15 - 29%, abrasion resistance 10 - 23% and reduced the sorptivity 25 - 43%. The concrete containing 40% FCA and 7% lime, replacing 47% of ordinary Portland cement (OPC) in total, exhibited strength of normal concrete or even more at all ages. Replacement of OPC by FCA alone has negative impact on compressive strength, whereas FCA along with lime has positive impact. It can be broadly concluded from the present study that FCA along with lime is a useful raw material for partial replacement of OPC up to 47%.

Sanghamitra Jena et al (2021)- The main intention of this research is to reuse the industrial by product ferrochrome slag and silica fume as a partial replacement of natural coarse aggregate and fly ash, respectively for the production of Geopolymer concrete with improved mechanical properties. Tests for compressive strength, splitting tensile strength and flexural strength of the GPC have been carried out at 7, 28 and 90 days of curing. The scanning electron microscope (SEM) was performed for the inspection of surface texture of the microstructure of the hardened samples. This investigation aims to evaluate the study of physical and mechanical properties of GPC by partially substituting SF as binder and charge chrome as coarse aggregate. SEM, XRD and FTIR tests are conducted to study the microstructure, mineral phase and vibration characteristics of GPC. Compressive strength, splitting tensile strength and flexural strength of GPC produced by replacing 30% FS and 10% SF increases by 38.9%, 47% and 20.4%. The implementation of SF and fly ash as a blended binder combined with FS or charge chrome as partially replaced NCA in GPC. The split tensile strength and flexural strength of GPC mixes were increased up to 30% of FS with 10% SF and then it was reduced. Also, the maximum strength was achieved at 30% of FS combined with 10% SF. The reliable relationship was established between CS and STS, CS and FS. The new proposed equation was found out by regression analysis.

Prasanna K. Acharya (2015)- The study the feasibility of using FA in concrete making as partial replacement of ordinary Portland cement (OPC). OPC was replaced by FA in four different substitution rates (10%, 20%, 30% and 40%) and 7% lime. Effect of lime and FA on compressive strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity and water permeability was investigated. In an effort to use FA significantly, research is carried out for its utilization in concrete as partial replacement of ordinary Portland cement along with lime, without sacrificing or even improving strength and durability properties of concrete. Results of the investigation indicate technical acceptability of FA, with lime as a substitute of cement on partial replacement.

Jyotirmoy Mishra et al (2022)- Earlier studies indicated that the reactive MgO reduces shrinkage crack and porosity, and accelerates the hydration and strength development. this objective, several geopolymer mixes are prepared by varying mix proportions of FCA and FA from 20 to 80% in the source mix. The petrographic and the SEM images indicated a good bonding between the binder and aggregates phase in the resulting mix. The role of MgO, one of the primary constituents of FCA, on strength development is established through the mineralogical and FTIR analysis. XRD analysis, revealed the formation of compounds like sylvine, K-feldspar mineral, and forsterite signifying the role of, Al, Si, Ca, K, Cl, and Mg available in the FCA indicating its dissolution character that helped in the strength development of the FCA-FA based geopolymer.

Jyotirmoy Mishra et al (2022)- The paper evaluates the possibility of developing open-air cured geopolymer concrete using the mixture of two metallurgical wastes such as ferrochrome ash (FCA) as the primary and ground granulated blast furnace slag (GGBFS) as the secondary source material. It is observed that the mixture containing 80% FCA and 20% GGBFS provides a compressive strength of 30.2 MPa, suitable for general construction works. At the same time, it requires 44.less embodied energy and releases 39.28% less carbon dioxide (CO2) gas than cement-based concrete of similar strength. The microstructural and mineralogical analysis, the presence of stable gel phases like N–A–S–H and C–A–S–H gels, and a series of rock-forming minerals were observed which were responsible for the strength development. The high chromium content in the source material is a great concern and requires further investigations for its immobilization before utilizing it as the construction material.

Prasanna K. Acharya (2016)- The possibility of using FA with lime for partial replacement of ordinary Portland cement (OPC) and FS for total replacement of natural coarse aggregates is explored in this research. The combined effect of FA with lime and FS-addition on the properties of concrete, such as workability, compressive strength, flexural strength, splitting tensile strength and sorptivity, were studied. A huge quantity of ferrochrome waste can be managed in preparation of good quality and sustainable green concrete that has ecological benefits.

Chethan Kumar B et al (2020)- This study is an attempt to develop a sustainable construction material, i.e., alkali activated slag (AAS) in combination with ferrochrome ash (FCA) as a replacement to ordinary Portland cement (OPC). The targeted design compressive strength is achieved with 25% FCA replacement 14 to GGBS in the AAS mortar system with Ms = 1.25. The test are compressive strength, split tensile strength and flexural strengh, The microstructure and mineralogical studies are undertaken to ascertain the formation of different hydration products with the aid of the scanning electron microscope (SEM) and the X-ray diffractometer (XRD). Replacing 100% Ground granulated blast furnace slag (GGBS)-based AAS mortars with FCA as binder in AAS mortars resulted in reduced compressive strength. As the 5 replacement of FCA increases in the AAS mortars, N-A-S-H is observed to be predominant with 6 the co-existence of C-S-H, C-A-S-H, and gismondine. Ecological and cost analysis studies show that FCA-based AAS mortars are found to be suitable with the benefit of having lower carbon footprint, lower embodied energy, and reduced cost.

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Chemical Composition ferrochrome ash

Material	SiO_2%	CaO	Al_2O_3%	Mgo%	Fe_2O_3	K_2O%	Na_2%	P_2O_5%	TiO_2%	SO_3	Cr_2O_3%	CL%	LOI	Reference
Ferrochrome ash (FA)	19.6	4.22	11.1	15.6	6.06	0.46	1.3	0.06	2.196	1.92	-	-	-	Tribikram Monhanty (2)
	19.6	4.22	11.1	15.6	6.06	-	-	-	-	1.92	-	-	-	Monalisa Sharma
	19.6	4.22	11.10	15.60	6.06	14.50	1.30	-	-	1.92	12.40	9.40	-	Prasana (3)
	19.6	4.22	11.10	15.60	6.06	14.50	1.30	-	-	1.92	12.40	9.40	-	Prasana (4)
	19.60	4.22	11.10	15.60	6.06	14.50	1.30	-	-	1.92	-	-	-	Prasana (5)
	19.6	4.2	11.2	15.6	6.1	14.5	1.3	-	-	-	12.40	-	-	Kumar
	19.10	3.14	10.91	23.60	7.84	11.42	2.46	0.07	N/A	-	9.892	-	-	Jyotirmoy Mishra (8)
	19.6	4.22	11.10	15.60	6.06	-	-	-	-	1.92	12.40	9.40	-	Prasana (6)
	19.6	4.22	11.1	15.6	6.06	0.46	1.3	0.06	2.196	1.92	-	-	-	

Physical properties Ferrochrome ash

Physical Properties	Specific gravity	Fineness	Colour	PH	Density (g/cm^3)	Particles retained on 45 micron sieve (wet sieving)(%)	Reference
Ferrochrome Ash(FA)	2.24	571	Grey	9.79	2.24	-	Acharya (6)
	-	571	-	-	2.24	6.50	Prasana (5)

3. MECHANICAL PROPERTIES

The effect ferrochrome ash on mechanical characteristics of the concrete samples for, compressive strength, split tensile strength and flexural strength containing natural find and coarse aggregate are reported below.

Compressive Strength

Compressive Strength is an important characteristic for determining the mechanical strength of concrete and hence necessary criteria in structural layout and detailing aspects. The average strength development of concrete cubes was studied at 7, 28 and 56 days. The test results depicted that as a consequence of the addition of Fly ash 10-30% and 3% of Ferrochrome ash, on the substitution of cement, the compressive strength got increased at all testing periods as compared to control concrete samples. The gain in strength is the consequence of the addition of FA and FCA The presence of SiO2 and Al2O3 are more in FA and FCA which is responsible for C2S and gives more strength in later age. The compressive strength of the mix with only OPC and FCA decreases by increasing the percentages of FCA, Tribikram Mohanty (11). The strength development of these two mixes N78S03 and N78S04 is found similar to or even more than (6.74 % and 5.41 %) the normal mix (N100C). RM and FA have less amount of CaO and SiO2 than OPC but rich in Al2O3. The concrete prepared using FA along with SF, Red mud can replace OPC up to 30% without compromising the compressive strength, Monalisa Sharma (2). The compressive strength of concrete 40% FCA and 7% Lime The results are summarized in Compressive strength test results revealed that ferrochrome ash concrete gained early age compressive strength 40% more than the normal concrete at the age of 7 days. At the age of 28 days, compressive strength of ferrochrome concrete is nearly 1% more than that of normal concrete, Prasanna K Acharya(3). Compressive strength got significantly increased on incorporation of ferrochrome ash FA and gypsum powder GP. At the age of 28 days, the percentage increase in compressive strength for mixes M3, M4, M5 and 1.49%, 9.28%, 22.06% respectively. Highest strength was achieved by concrete mix M5 having 10% gypsum powder GP with 30%ferrochrome ash FA. In M3 and M4 mixes the strength decreased as compared to M5 mix containing 10% gypsum powder GP with 30% ferrochrome ash FA but the strength was more than original concrete mix. The maximum replacement of ordinary Portland cement OPC was considered 40%, Shrinu Mohanty (14

Split Tensile Strength

The results at above age have been depicted in the results revealed that due to the inclusion of FA 10-30% and 3% FCA on replacement of cement, the split tensile strength got increase in comparison to normal concrete, Tribikram Mohanty (11). It is found that the concrete mixes N78S03 and N80R10 shows comparable results at 28 days with normal concrete mix (N100C). Compressive strength qualitatively governs the other most desired properties of concrete similar effect is observed due continued pozzolanic reaction and formation of more C-S-H gel in presence of FA with SF. The strength development in the mix, containing 19% FA and 3% Silica fume is found more with age when compared to other mixes, Monalisa Sharma(2), There was a consequent increase in split tensile strength due to incorporation of ferrochrome ash FA and gypsum powder GP. At the age of 28 days, the percentage increase in split tensile strength for all mixes M1, M2, M3, M4, M5 as compared to original concrete was found to be more. Highest strength was achieved by concrete mix containing 10% gypsum powder GP with 30% ferrochrome ash FA, Shrinu Mohanty (14). Splitting tensile strengths of all concrete mixes at the ages M1, M2, M3, M4, M5 And of 28, and 180 days. Splitting tensile strength further increased 1.45–4.58%, 1.37–5.50% and 2.71–11.04% in comparison to control mix (M-1) due to the inclusion of lime and FA. Due to the inclusion of lime and FA. Splitting tensile strength continued decreasing with higher dosages of FA, but maintained more than the control mixes at all ages, Prasanna K Acharya(5).

Flexural Strength

The flexural strength of prisms containing 10-30% of FA and 3% FCA, on replacement of cement was examined at 28 and 56 days. The results at the above age are depicted in Data obtained from the study revealed that due to the addition of FA and FCA, on the substitution of cement, the flexural strength got increased as compared to control concrete samples, Tribikram Mohanty (11). The samples N78S02, N78S03 and N78S04 the good results as compared to N100C. During the reaction the interfacial transitions zone (ITZ) among matrix and aggregate become denser and width of micro gaps decreases, which is responsible for the upgrading of strength, Monalisa Sharma (2), The flexural behaviour of RC beams, containing 40% FCA and 7% lime (replacing 47% OPC) is comparable to that of normal concrete beams. The ultimate load carrying capacity of FCA concrete beams is found 8.33% more than normal concrete beams, Prasanna (), The percentage increase in flexural strength for all mixes M1, M2, M3, M4, M5 as compared to original concrete was found to be more. Highest strength was achieved by concrete mix containing 10% gypsum powder GP with 30% ferrochrome ash FA, Shrinu Mohanty (14). Increase in flexural strength on the replacement of natural coarse aggregate by FS coarse aggregate is due to the improved mechanical properties of FS. Increase in flexural strength on the inclusion of FA and lime is due to filling of gaps and micro voids on formation of more C-S-H gel, Prasanna K Acharya (7).

Workability

The workability is controlled by particle size, shape, packing effect and surface texture of the material. It is observed from that the workability of the mix with only OPC and FA decreases on increasing percentages of FA because of the larger particle size, spherical shape and packing effect. Workability increases with the addition of RM and SF respectively in ascending order, Monalisa Sharma (2), The slump values of the control concrete with natural coarse aggregate (M-0) and control concrete with FS coarse aggregate (M-1) were recorded at 66 and 90 mm. On inclusion of various (10–40)% FA, with 7% lime in concrete mixes M-2, M-3, M-4 and M-5 containing FS coarse aggregate, the slump values were recorded as 82, 75, 68 and 57 mm, respectively. The workability increased on replacement of natural coarse aggregate by FS aggregate, but decreased on inclusion of lime and FA, Prasanna K Acharya (5)

Sorptivity

Sorptivity of the concrete mix containing FS coarse aggregate and the highest dosage of FA (M-5) is found to be less than that for the control mixes M-0 and M-1 at all ages. This is because of improved transport properties in the lime activated FA system in the formation of flocks inside the matrix due to lime hydration, Prasanna K Acharya (5).

4. CONCLUSION

- Ferrochrome ash (FCA) possesses physical and mechanical properties that are superior to different types of natural materials including limestone. Partial replacement of traditional sand with ferrochrome ash decreases the tensile splitting strength, compressive strength and flexural strength of concrete at all ages.
- As per the current research, it is visualized that samples of concrete with fly ash and ferrochrome ash Cement + Fly Ash + Ferrochrome Ash, has the maximum compressive strength.
- The increase of N-A-S-H reduces the C-S-H, C-A-S-H, and gismondine in the final composition of the ferrochrome ash (FCA) based alkali activated slag (AAS) mortars when compared with 100% GGBS-based AAS mortars.

- Ferrochrome ash supplemented with FA, SF and RM effectively replaces the cement up to 30% without compromising the compressive strength.
- The mechanical properties of Ferrochrome ash supplemented with industrial wastes like Silica fume and Red mud as partial replacement of cement in concrete.
- The compressive strength increases with the increment in the proportion of FA and Ferrochrome ash increases as partial replacement of cement.
- Higher values of co-relation coefficient confirm the strong relationship between strength and durability properties of concrete containing FA and lime.
- This investigation indicate technical acceptability of Ferrochrome ash, with lime as a substitute of cement on partial replacement.
- Finally, it is essential to update the legislations and engineering design specifications to regulate the use of ferrochrome ash in different civil engineering applications, including concrete production.

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