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Study on the Performance of Concrete by Partial Replacement of Fine Aggregate With Scrap Steel Mill Scale

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ABSTRACT

Cement concrete is one of the most versatile and widely used materials throughout the world. It is generally composed of three phases: aggregates, cement paste and a transition zone between cement and aggregates. Aggregates form the skeleton of concrete. Approximately, 3/4th volume of concrete is made of aggregates (Fine and Coarse). Aggregate is considered as the most important constituent of concrete since it contributes to the fresh and hardened properties of concrete. River sand is the most common fine aggregate used in concrete. Nowadays, there is a huge demand for natural fine aggregates in the construction world since modernization and urbanization which lead to over exploitation of natural river sand and it results in depletion. Hence, in order to preserve natural resource and to develop sustainable environment, it is important to replace a suitable material for fine aggregates in concrete. On the other hand, Industrial Waste Management is one of the most emerging fields associated with the environmental safety. Most of the industrial solid wastes are dumped as landfills and cause environmental pollution. In order to provide a better solution to this problem, nowadays, utilization of large quantities of metal industry waste materials like copper slag, steel slag, blast furnace slag, foundry sand, steel mill scale etc., as a partial replacement of fine aggregates are being practiced in the construction industry.

Steel is manufactured from iron ores. The various processes involved in steel manufacturing are Sintering, Blast furnacing, Basic oxygen furnacing, casting and rolling. Hence, there are several solid wastes are generated during steel manufacturing process. Sinter plant, refractory material plant, basic oxygen furnace, steel melting shop and rolling mills are the main sources of solid waste generation in a steel plant. The major solid wastes in a steel plant are coke dust, blast furnace slag, LD slag, scrapped steel mill scales, mill sludge, fly ash, SMS slag and etc., Some of these solid wastes might have potential as to be used as a substituent material to the concrete ingredients.

Keywords: Cement Concrete; Partial Replacement, Fine aggregate, Scrap Steel, Mill Scale.

1. INTRODUCTION

The most extensively used construction material called concrete primarily consists of filler materials bound together by a binder. Admixtures may be added sometimes to enhance the properties of concrete. Aggregates occupy approximately 70% of the volume of cement concrete. The global volume of natural resources consumed in infrastructure development increased 23-fold between 1900 and 2010. Sand and gravel account for the majority of these main material inputs (79 percent, or 28.6 gigatons per year in 2010) and are the most widely exploited resources on the world. Torres et al. (2017) Currently, Indian construction sector contributes a share of 6.3% in Gross Domestic Product and this share is predicted to reach up to 13% by 2028. This rapid growth in construction industry leads to aggregate demand. At present, India is facing meticulous deficiency for construction aggregates.

1.2 Background of the Study

As the use of concrete has been increased in all type of construction works, the demand for river sand has also raised. The presence of plenty of silica content in the river sand made it the best choice for concrete production and hence the demand for river sand increases. This demand causes tremendous quarrying of river sand which causes severe damage to the river system. This sand mining has also created severe environmental problems, loss and displacement of livelihood. Sand mining in India is mostly unregulated. Hence the process of mining is easy with very minimal effort. This unorganized sand mining by several small investors has made tremendous changes in the cost of the sand across various parts of the country. Government has enforced laws to prevent over exploitation of river sand. In order to preserve river sand resource, the Ministry of Environment Forest and Climate Change (MoEF & CC) has formed the guidelines for Sustainable Sand management in the year 2016, which deals with sand mining management in the nation. The Figure 1.1 shows the variations in the sand demand in India during the past two decades.

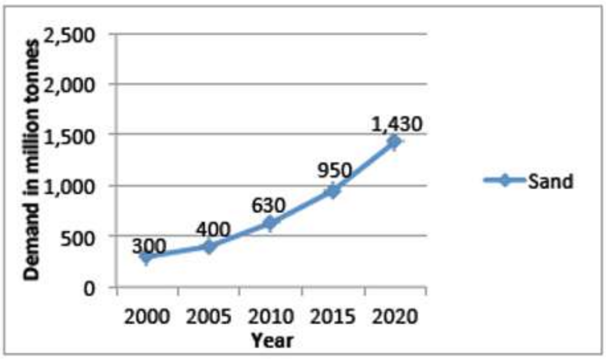


Figure 1.1 Estimated fine aggregate demand in India

On the other hand, a huge quantity of solid waste has being produced throughout the country in various industrial activities. Direct disposal of these waste materials into the environment causes serious ecological issue. One of the resourceful techniques to preserve natural river sand is the partial substitute of solid waste materials for fine aggregates in concrete. Some studies on the use of solid waste like plastic, rubber, glass fibre, Ground Granulated Blast furnace Slag, copper slag, sintered sludge pellets, steel slag, foundry sand, demolition waste, kiln dust and others as a partial substitute for fine aggregate in concrete have already been made. Various positive impacts like solid waste management, Sustainable development, conservation of natural resources, low cost & eco friendly construction have been reported by the use of the waste materials in concrete. The By-product called Steel mill scale produced from the steel industry has the competence which is to be replaced for natural river sand in concrete.

1.2.1 Indian Steel Sector-General

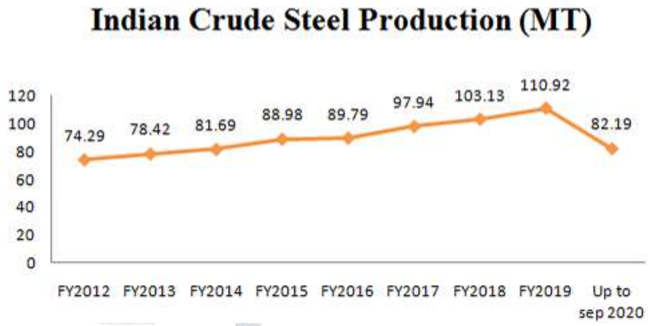


Figure 1.2 Steel Production in India

India's finished steel consumption in the year 2018-19 was 98.71MT and it is expected to reach 230MT by the year 2030-31. The per capita consumption of steel in India is expected to reach 160kgs by 2030-31. The major steel producing companies in India are Tata steel, SAIL, JSW steel, Hindalco, Jindal steel and NMDC. There are 10 major integrated steel plants present in India. They are Tata iron and steel corporation (TISCO), Bhilai steel plant, Visvesvaraya iron and steel plant, Durgapur steel plant, Chandrapur ferro alloy plant, Bokaro steel plant, JSW steel plant, Vizag steel, Salem steel plant, and IISCO steel plant.

However, manufacturing process of steel generally accompanies with the large amount of solid state waste materials like Sludge, slag, dust, steel mill scale, etc. World Steel Association has reported that to produce 1 tonne of steel, steel industries need 1.15 tonne of raw materials. These solid wastes generated in the steel industries during various production processes can be reused by steel industry itself or used for other industries. The solid waste management from steel industries helps to reduce carbon dioxide emission and prevent landfills.

1.2.1 Steel Mill Scale

In general, three kinds of waste materials were generated in steel industries and they were solid, liquid and gaseous wastes. To produce 10 Million Tonnes per Annum (MTPA) of crude steel, approximately 6MTPA of solid wastes were generated. Blast furnace slag, blast furnace dust, LD slag, LD sludge, steel mill scale, mill sludge, coke breeze, and coke dust were among the solid wastes produced by the steel industry. Steel mill scale is a kind of iron oxide produced on steel surface during hot-rolling, reheating, hot forming and conditioning operations. It is formed when oxygen carrying gas reacts with steel surface during hot rolling process to corrode the steel in to layers of ferrous oxides. It is generally removed from the steel surface by water and subsequently collected using gravity separators. Steel mill scale is a brittle material. It is rich in iron content, consisting of mixture of iron oxides like hematite (Fe_2O_3), wustite (FeO) and magnetite (Fe3O4). Steel mill scale is considered as non- hazardous scrap material. The material is hard, porous and brittle in nature.

Manufacturing process of steel mill scale includes continuous casting, reheating and rolling process in steel plants. Steel mill scale formation results in loss of steel yield in the industry. It also deteriorates the surface smoothness of the finished products. Presence of steel mill scale on the surface of the steel speeds up the process of corrosion in steel since it is polluted with oil and water. Therefore, steel mill scale should be removed from the steel surface before the application of any coating on the surface. Removal of steel mill scale is a tedious process. Flame cleaning or abrasive blasting method can be adopted to remove steel mill scale. Approximately 6500 to 8500 tonnes of steel mill scale was produced from a single steel plant in India annually. The overall annual production of steel mill scale from Indian steel plants was estimated approximately to 18-20 million metric. Table 1.1 reveals the plant wise steel mill scale generation.

Table 1.1 Plant-wise steel mill scale generation (2017-18 and 2018-19) (in Tonne/yr)

Steel Plant	2017-18	2018-19
Tata steel	98761	102652
SAIL	67683	57362
JSW steel	45000	NA

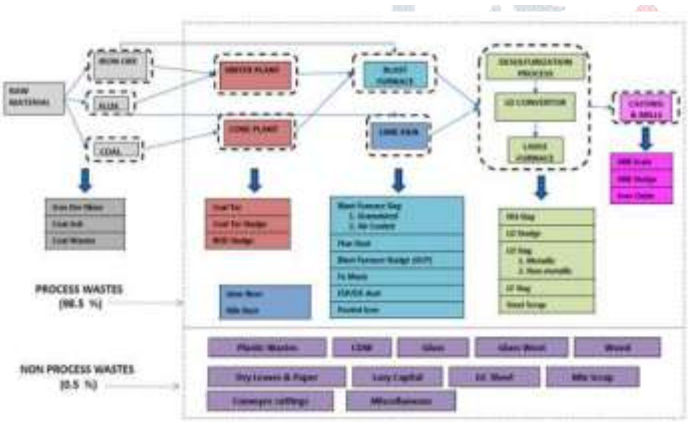


Figure 1.3 Solid waste generations at steel industries

Figure 1.3 shows the solid waste generation at steel industries. The quantity of steel mill scale generated in the rolling mill depends on the rolling practice adopted and the type of reheating furnace used. In general, steel mill scale generation is about 1 – 3% of weight of steel rolled in the rolling mill. Steel mill scale is classified into two types i.e., primary scales and secondary scales. Primary scale is one which is formed during heating process in the heating laboratory, where the steel is heated to rolling temperature. It is blackish blue in colour. It is also known as furnace scale. It is removed by hydraulic descaling process. Primary scales are made of three iron oxide layers and they are wustite, magnetite and hematite. These primary scales are removed before rolling process. Secondary scale is formed in the roughing and intermediate rolling mills. The primary steel mill from the steel surface was removed before rolling process. But, due to the presence of heat on the surface of the steel, it again oxides immediately and produces secondary scales. These scales thus produced are known as residue scales. They are blue in colour. They mainly consist of ferric-oxide. The thickness of the steel mill layer on the steel surface is less than 0.1mm. The steel mill scale is formed in various sizes from microns to millimeters. Steel mill scale is generally recycled and used in sintering process. Steel mill scale is an exportable material because it has no export charges. The steel mill scale produced from the Indian steel plants is exported to various parts of the world. But, the main problem associated with steel mill scale export is the process which has lengthy documentation works. Also, the quantity of steel mill scale from each steel plant is less and it is difficult to export in bulk quantities from a single source point.

1.3 Need for the Present Study

The review of literature has covered various studies utilizing steel by-products (Steel slag, blast furnace slag, ferro nickel slag etc.,) in concrete as a partial replacement for aggregates which evidences increasing research significance in this area. Since a wide gap was identified in the previous researches regarding the effective usage of steel mill scale in particular as fine aggregates' in concrete without depicting the micro-structural properties and detailed analysis other than mechanical properties. Also fresh, hardened, durability, structural and micro-structural properties of concrete made of steel mill scale aggregates were not evaluated thoroughly. Hence, there are still numerous scopes available in the present study to scrutinize the possibility of utilizing steel mill scale in concrete.

The present study will reflect the micro-structural behavior along with the durability aspects in addition to the physical and structural properties of the material thereby increasing the options for management of industrial wastes by incorporating steel mill scale as an active ingredient in concrete, which in turn indirectly leads to the conservation of natural resources.

1.4 Objectives of the Present Study

Utilization of steel mill scale as fine aggregate in concrete helps not only to reuse the by-product as a resource but also to preserve natural river sand. The definite objectives of the studies were

1 To conduct investigation on steel mill scale's influence on concrete's properties and to identify appropriate replacement percentages of steel mill scale in concrete for the replacement of fine aggregates and to evaluate workability, mechanical and durability properties of concrete.

2 To verify the results on strength using micro-structure analysis of the concrete.

3 To establish the benefits of using steel mill scale in concrete in terms of sustainable and environmental advantages and to give confidence in using the same in conventional concrete.

1.5 SCOPE OF THE PRESENT STUDY

To investigate the influence of steel mill scale particles as a partial replacement for fine aggregate on the concrete's mechanical properties, tests for compressive strength, split tensile strength, flexural strength micro-structure analysis and other durability studies of concrete were focused in this study. This investigation also targets to establish the most appropriate mix proportion that could produce good quality concrete of desirable strength and durability performance. This research work focuses on the usage of waste materials from the industries and to attain sustainable development in the construction sector.

2. LITERATURE REVIEW

2.1 General

This chapter deals in reviewing previous studies which deals with concrete, aggregates, steel by products, production and properties of steel mill. Several articles have been studied. Feasibility analysis on the partial replacement of steel mill scale for fine aggregates in concrete was made.

2.2 Background

Neville & Brookes (2010) described the Concrete, in its broadest sense, refers to any product or mass created through the application of a cementing medium which is the outcome of the reaction between hydraulic cement and water. However, such a definition could now cover a wide range of products, including concrete made with various types of cement containing pozzolan like fly ash, blast furnace slag, micro silica, additives, recycled concrete aggregates, admixtures, polymers, fibres, and so on; and this concrete can be heated, streamed-cured, autoclaved, vacuum treated, hydraulically pressured, shock-vibrated, extruded, and sprayed. Habert et al. (2020) stated that Cement consumption has increased tenfold in the last 65 years, a significant change considering the steel output has only increased by a factor of three. Indeed, cement accounted for 36% of the 7.7 giga-tons of CO2 emitted globally by building activities in 2010, while steel, plastics, aluminium, and brick accounted for 25%, 8%, 4%, and 1% respectively. It's worth noting that only half of the cement used in concrete remainder goes to manufacture of blocks, mortar, plaster and etc. Concrete builds up in the Earth's crust and is now considered one of the Anthropocene's markers, with an estimated 900 giga-ton added since the industrial revolution began. The rate of concrete accumulation is attributed to the global population's rapid urbanisation. By 2050, the worldwide urban population is expected to grow by 2.5 billion people, with Asia and Africa accounting for the majority of this growth. This population growth is expected to produce a surge in demand for building materials, especially concrete, due to the need to fill the existing large housing gap and for the future infrastructure development.

Mindess et al. (2003) stated that major portion of our day-to-day life depends on concrete directly or indirectly. Concrete is the predominantly used construction material such that many achievements of modern civilization directly depend on concrete. It is a compound material contains granular aggregates entrenched inside a matrix of cement paste which fills the pores in between the aggregates and binds the particles together. It is made of constituent materials like cement, fine aggregates, coarse aggregates, water. etc., Aggregates are inert filler materials whereas cement is chemical product which reacts with water to form a binder gel that binds the aggregates together.

Ma Houser et al. (2017) described that hot rolling process is inevitable in steel production. Hot rolling step helps to produce finished products. At first, semi steel products were heated at 1523K in the heating furnace where on the surface of steel, steel mill scale is formed due to oxidizing atmosphere present in the furnace. Then the steel products were transferred to the rolling mill where descaling process is done. Therefore, a huge quantity of steel mill scale is generated along with the steel products. The steel mill scales were separated by spraying the cooling water under pressure in the hot rolling process and they were carried away along with the waste water. The descaled water is kept undisturbed in the settling pit where steel mill scale particles will settle down under the action of gravity. These steel mill scales are generally oily because the cooling water is generally oily. This is because the bearing and hydraulic machines in the steel plant generally leak oil. The oily steel mill scale is cleaned by De-oiling process where the oil present in the steel mill scale is made to volatilize at high temperature.

Keleştemur & Arıcı (2020) described about a kind of solid waste produced in the steel industry called Steel Mill Scale. During hot rolling process, it is developed on steel products' outer surfaces like plates, profiles or sheets. Steel mill scale is rich in iron oxide mostly ferric oxide. The particles are bluish black in nature. Steel mill scale is initially considered as a waste material and they were dumped as landfill. However, the prospect of using steel mill scale as a fine aggregate replacement in concrete has grown recently. The utilization of waste steel mill scale in manufacturing of construction materials helps in reduction of their disposal problems. Steel mill scale mostly consists of hematite (Fe2O3), iron (Fe) and magnetite (Fe3O4), iron (Fe) as revealed by steel mill scale's X-ray diffraction analysis. Also higher specific gravity of steel mill scale is recorded, when compared to the specific gravity of natural river sand. While, compared to natural river sand, water absorption of steel mill scale particles is less. Murthy et al. (2017) investigated the feasibility for the potential application of steel mill scale instead of fine aggregate in concrete. Steel mill scales are blue black materials created during the hot rolling of steel, according to them. They are flaky and their thickness is less than millimetres. Steel mill scale can be utilised to make high-density concrete, according to the researchers, because its specific gravity is double that of fine particles. Also, the smaller particle size distribution along with insignificant absorption of water by steel mill scale further results in denser concreting. The presence of chemical compounds like Fe2O3, Al2O3 and SiO2 in steel mill scale evidences the strength attainment in concrete. The XRD results obtained revealed that composition of steel mill scale mainly includes hematite, wustite, magnetite and silica contents. From the investigation, they have concluded that steel mill scale is the best suitable alternative for partial replacement of fine aggregates. From the image of particle size distribution, inference can be made that nearly 90 percentages of steel mill scale particles lies below 1mm. This will lead to dense concrete formation. Thus, with the addition of steel mill scale as partial replacement for fine aggregate, the mechanical strength of concrete obviously increases with. Figure 2.1 shows the Particle size distribution of steel mill scale.

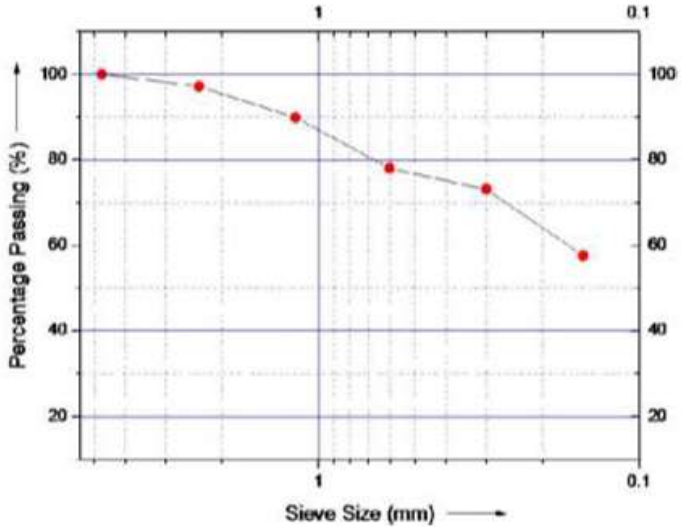


Figure 2.1 Particle size distribution of steel mill scale (Murthy 2017)

Suleyman et al. (2015) investigated about heavy weight aggregate's effect on the properties of concrete with heavy weight. They've tried steel mill scale, steel slag, iron ore and two forms of barite, among other heavy-weight aggregates. Among all other aggregates steel mill scale aggregate produce high density concrete. The absorption of water in the concrete was less than 0.8% for all the aggregates. The grading curves obtained for different aggregates were approximately similar to the fuller parabola. The Figure 2.2 revealed that steel mill scale's particle size distribution was same as that of natural river sand.

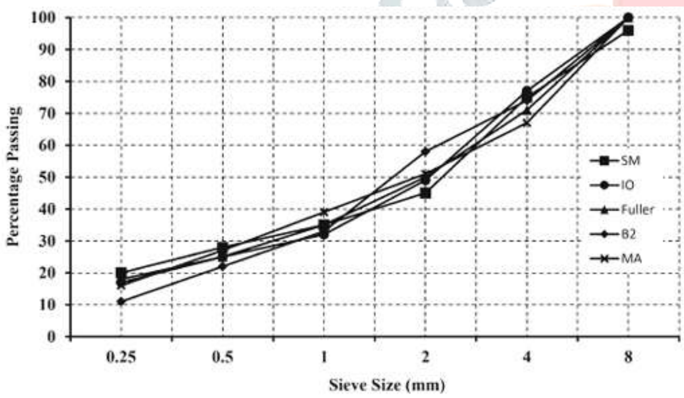


Figure 2.2 Combined grading curves of aggregates (iron ore, steel mill scale, magnetite and barite 2) (Suleyman, 2015)

Ozturk et al. (2020) experimented the morphology of small and large size steel mill scale particles. They reported that small steel mill scales are oval and agglomerated where as large sized steel mill scales are coarse and melted in morphology. Figure 2.3 reveals the SEM images of steel mill scale samples.

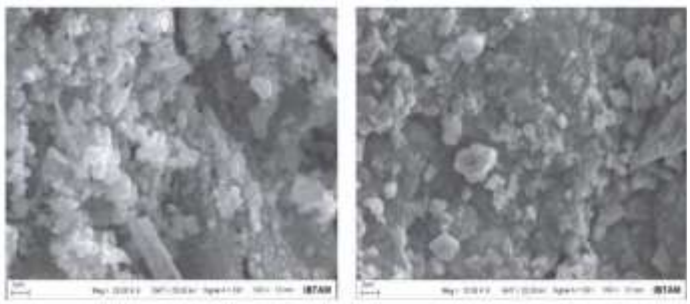


Figure 2.3 SEM images of steel mill scale samples (Ozturk 2020)

SEM analysis results revealed the fine nature of steel mill scale. Steel mill scale particles appeared nonporous texture and they were irregular in shape. The size of the steel mill scale particles varied from 1 to 50 microns (Erika 2016). Figure 2.4 shows the SEM micro-graph of steel mill scale.

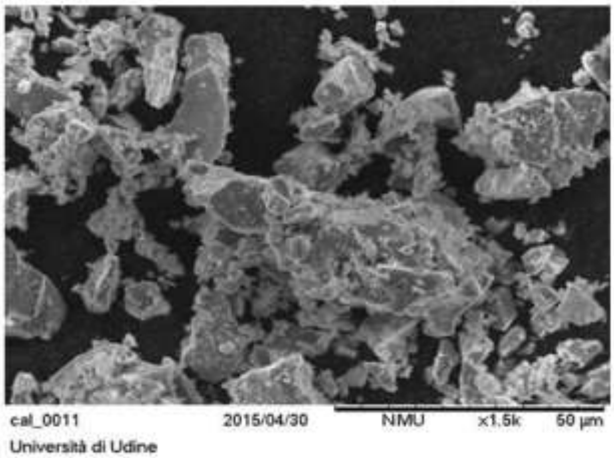


Figure 2.4 SEM micro-graph of steel mill scale (Erika 2016)

The X-Ray Diffraction pattern results on steel mill scale revealed that peaks of steel mill scale indicated the presence of high concentration of magnetite and wustite (Ozturk et al. 2020). The XRD pattern evidences that steel mill scale particles contain mixture of iron oxides like hematite, wustite and magnetite (Oguzhan et al. 2019). Figure 2.5 and Figure 2.6 show the XRD pattern of steel mill scale.

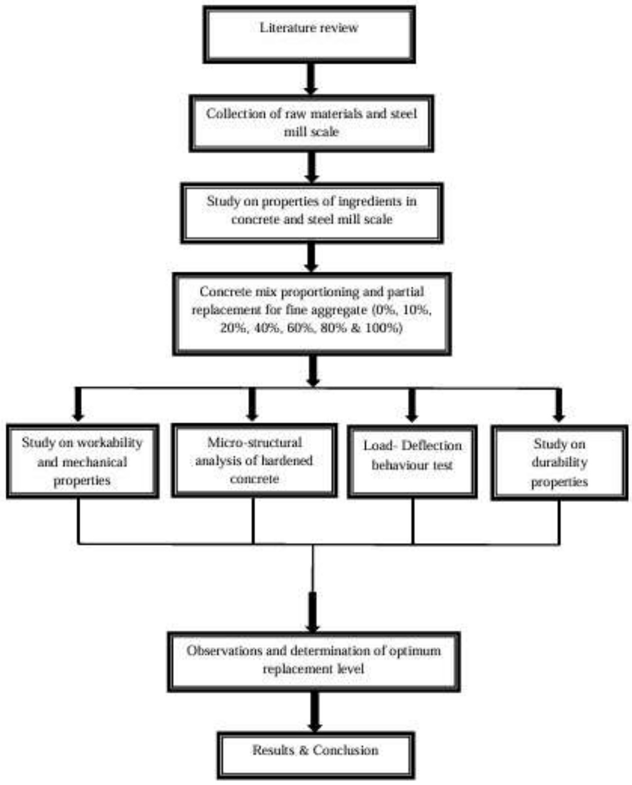
Ozturk et al. (2020) carried out an experiment on usage of steel mill scale aggregates as replacement of natural river sand. The study revealed that with the effect of steel mill scale, the mechanical properties of cement mortar increased. Natural river sand replaced with 15% of steel mill scale improved the concrete compressive strength by 23.12% due to the ferromagnetic properties and cubic crystal structure of steel mill. Oguzhan et al. (2019) examined the properties of cement mortar by substituting steel mill scale in place of river sand. The investigation revealed that partial replacement of sand with steel mill scale yield better results on compressive strength since rough surface of steel mill scale produce good adhesion between cement mortars. Also, it was reported that steel mill scale particles prevented the crack propagation in concrete. It was shown that the test results of compressive strength and results of ultrasonic pulse velocity test of concrete samples were similar to each other nearly. The pulse velocity values samples made of varying percentage of steel mill scale aggregates varied to 3.86km/s from 3.35km/s, thus indicated good quality of concrete. Erika et al. (2016) reported that the compressive strength of cement mortar was improved by 10% by substituting Natural River sand with steel mill scale aggregate. Also, the water absorption, thermal conductivity and apparent density results showed better improvement with the incorporation of steel mill scale. They have reported that steel mill scale incorporated sample as a high performance mortar. It was detected that the values of compressive strength have maintained 5% of standard deviation of the average value. The samples' water absorption decreased due to the non-porous surface of steel mill scale particles.

Mohamed alwaeli et al. (2012) focused on the properties of concrete due to the influence of steel chips and steel mill scales. The results on compressive strength of concrete showed increased with the replacement of steel slag and steel mill scale. At 25% replacement of steel mill scale, maximum strength was obtained. With the addition of slag and steel mill scale, density of the concrete increased. The concrete thus obtained shows better resistance to gamma radiations. Akindahunsi et al. (2008) investigated the use of billet scale for partial substitution of fine aggregate. Billet scales are by-products obtained from the steel rolling mills. The research results revealed that due to the effect of billet scales, split tensile strength and compressive strength of concrete were improved. Anupam et al. (2015) made a study on cement mortar optimization using steel mill scale aggregates. Their experimental results proved that the partial replacement of steel mill scale instead of river sand improved both the strength on compression and strength on split tension. Steel mill replacement of 0, 20, 40, 60, 80 and 100% was utilized in this experiment. With 60% of steel mill scale replacement, the maximum strength on compression and split tension of the cement mortar was obtained whereas at 40% replacement of steel mill scale, the maximum strength on compression in concrete was obtained by curing for 28 days. Also the strength on compression for all the percentage replacement levels excluding 20% replacement exhibited better results than the control specimen. Bulk density of the concrete also showed gradual increase with the increasing steel mill scale percentages. Steel mill scale aggregates on replacement of enhanced the bulk density of concrete by 38% for 100% replacement. They have made a conclusion that the performance of steel mill scale aggregates is influenced by the contaminants present in it. Mohamed Alwaeli (2016) investigated about concretes made waste from the iron and steel industries such as scale and steel chips as substitute for sand. The percentage replacement of natural sand varies from 25% to 100% by weight of sand with steel chips and scale. In this process, in order to shield against X-ray radiation, they investigated mixed concrete shield's compressive strength and comparison was done on mixed concrete shield's thickness, with ordinary concrete shield's (OC-0) thickness. The results showed that as the mixing ratio of scale and steel chips waste aggregate increased, the thickness of mixed concretes decreased. The data showed that better strength was obtained for concrete mixed with waste steel chips than ordinary concrete, while an addition of over 25% in the case of concrete mixed with scale waste, brought decrease in compressive strength. Thus the concrete produced showed better performance and can therefore be used in radiation attenuation activities, as an alternative to conventional concrete. Furlani et al. (2016) investigated the reports dealing with the recycling of steel scale waste based on the results of some experiments in the production of mortars. In this paper, the preparation of materials were done by mixing commercial natural aggregate, steel scale waste, commercial CEMII/B-LL cement, water and super-plasticizer. Natural aggregate was replaced with steel scale waste in different proportions namely (5, 10, 20, 30 and 40 weight in percentage). After 28days of curing, high compressive strength was exhibited by all hydrated materials and they could be classified as high performing mortars as an importance of their low water absorption; however with increase in the SSW addition, strength decreases progressively. As a function of addition of SSW addition, an increasing trend has been displayed on the apparent density of materials due to SSW's high specific gravity with respect to the ordinary aggregates. Highest thermal conductivity values were shown by samples containing 5% and10% of SSW and were explained by taking into account, the higher SSW thermal conductivity when compared to that of an ordinary concrete coupled with their low absorption of water.

Iluțiu-Varvara et al. (2020) looked into the possibility of steel mill scale being recycled when used as a partial replacement for fine aggregate in mortar production. The usage of steel mill scale waste in construction industry provides best solution for conservation of natural river sand. It also helps to reduce environmental problems related to steel mill scale disposal. The steel mill scale used in this paper was oven dried at 105ºC and they were crushed and used. The steel mill scale was substituted in 10% and 20% proportions of natural river sand. Casting of mortar samples were done and tested for its density, consistency, and water absorption coefficient, compressive and flexural strength. From the test results, it is found that with the addition of steel mill scale, density of the mortar increases. Also, the water absorption decreases due to the influence of steel mill scale. Mechanical strength of the samples of mortar with the aggregates of steel mill scale was higher than the standard sample. Al-Otaibi (2008) has investigated the feasibility of using recycled steel mill scale aggregate in concrete as fractional replacement for fine aggregates. Using X-ray diffraction, steel mill scale's mineral composition was determined. Different mortar mixes were cast with partial replacement (0%, 20%, 40%, 60%, 80% and 100%) of steel mill scale for fine aggregate. The specimens were tested for both compressive and flexural strengths. Test results found that compressive and flexural strength of mortar was improved with 40% replacement of steel mill scale aggregates.

3.0 Methodology

This chapter deals about research methodology and the detailed study on constituent materials properties like fine aggregate, steel mill scale, coarse aggregate, cement and reinforcement bars used in the research. Detailed physical, chemical and micro-structure properties of the concrete ingredients are discussed in this section. Since strength of concrete depends directly on material properties, a thorough investigation on the material properties was done. It will also help to derive the accurate concrete mix proportioning to attain the target strength. Also, this chapter describes the various testing methods for fresh and hardened concrete, specifications of the specimens used for various testing, method of casting specimens and curing methods.



3.1 Material Properties

3.1.1 Cement

Cement is a material used in concrete for its binding property which helps to bind the aggregates together to form a solid dense concrete mass. Grade 33 Ordinary Portland cement, available in nearby markets was used. The standard consistency of the cement used was 31%. Test on cement's chemical and physical properties was done as per IS 4031-1991 and the Tables 3.1 and 3.2. tabulated the results.

Table 3.1 Physical properties of cement

Particulars of test	Test results	Requirements based on IS 4031 :1988
Specific gravity	3.15	-----
Fineness(m^2/kg)	350	Min. 300
Initial setting time (min)	31	Min. 30
Final setting time (min)	171	Max. 600
Soundness (mm)	1	Max. 10
Standard consistency (%)	31	-----
compressive strength on 7 days (N/mm^2)	29.92	Min. 22
compressive strength on 28 days (N/mm^2)	34.12	Min. 33

Table 3.2 Chemical composition of cement

Test particulars	Results	Requirements based on IS 1489:1991
Loss on ignition (%)	1.13	Maximum 5
Magnesia MgO (%)	1.67	Maximum 6
Sulphuric Trioxide (SO_3)	2.41	Maximum 3.5
Insoluble materials	28.97	-----

Table 3.3 Physical properties of fine aggregate

Test Particulars	Results
Specific Gravity	2.43
Bulk Density (g/cc)	1.67
Bulking of Sand (%)	16.28
Relative density (kg/m^3)	36.36
Void Ratio	0.76
Fineness modulus	2.83

Table 3.4 Composition of chemicals in fine aggregates

Test Particulars	Results
Loss on Ignition (%)	1.24
Silica (SiO_2) (%)	79.93
Iron (Fe_2O_3) (%)	4.4
Aluminum Oxide (Al_2O_3) (%)	10.92
Calcium Oxide (CaO) (%)	1.18
Magnesium (MgO) (%)	1.66

Table 3.5 Mechanical properties of coarse aggregate

Test Particulars	Results
Specific Gravity	2.60
Bulk Density (kg/m^3)	1636
Test on aggregate impact value	12.8
Test on aggregate crushing value	26.67

4.0 Results and Discussion

A semi-solid material made of cement, aggregates and water that can be moulded into any desired shape is known as fresh concrete. Though hardened state of concrete is the final output, its properties on mechanical and durability aspects depends only on fresh concrete's properties. Generally, fresh concrete should be easily to mix, transport and handle during the entire casting process. Several tests on workability were conducted to study the concrete workability in fresh state.

4.1 Slump Cone Test

In order to find fresh concrete's workability slump cone test was conducted. Slump values were determined for concrete made of different percentage replacements with steel mill scale for fine aggregate and Table 4.1. depicts their results. Figure 4.1 shows the pictorial representation of variation of slump values for different replacements.

Table 4.1 Slump value for various levels of steel mill scale replacement

Steel mill scale replacement (%)	Slump (mm)	Workability
0	75	Medium (shear)
20	70	Medium (shear)
40	50	Medium (true)
60	50	Medium (true)
80	45	Low (true)
100	40	Low (true)

From the Table 4.1, it is clear that slump value for control mix with 0% fine aggregate replacement is 75mm. As the percentage replacement of steel mill scale increases, slump value decreases gradually from 75 mm to a least value of 40 mm at 100% replacement. Thus, the increase in percentage replacement of the steel mill scale harshly affects fresh concrete's workability (Singhal et al. 2015 and Ozturk et al. 2020).

4.1.2 Compaction Factor Test

For various quantities of steel mill scale replacements, a compaction factor test was performed to determine the workability of fresh concrete. The results of the tests are shown in Table 4.2.

Table 4.2 Compaction factor for various steel mill scale replacements

Steel mill scale replacement (%)	Compaction factor
0	0.99
20	0.97
40	0.96
60	0.96
80	0.95
100	0.93

Table 4.2 reveals that compaction factor values of concrete produced with various steel mill scale replacement decreases upon the addition of steel mill scale. Value of compaction factor decreases from a start of 0.99 at 0% replacement to 0.93 at 100% replacement. Similar to slump cone results, compaction factor results also confirms that steel mill scale addition in concrete reduces the workability of concrete.

The shape and surface roughness of the steel mill scale have a noteworthy effect on the water needed for concreting. The internal friction between paste of cement and steel mill scale particles increases because of its high roughness at surface. Also, steel mill scale particles are finer than natural sand. The fineness of steel mill scale leads to increased surface area. Hence, more quantity of water is needed to bind steel mill scale with concrete and therefore workability of concrete reduces naturally (Singhal et al. 2015 and Ozturk et al. 2020).

4.1.3 Density of Fresh Concrete

Density of conventional concrete along with the concrete made by various replacements (20%, 40%, 60%, 80% and 100%) of steel mill scale for fine aggregates was determined and results were represented in Figure 4.3.

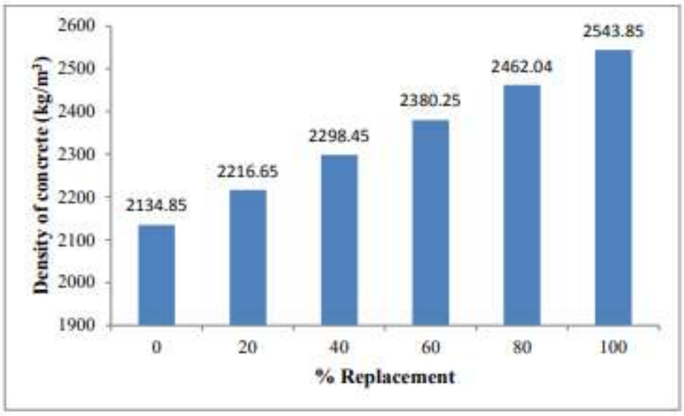


Figure 4.3 Concrete density for various replacements

Figure 4.3 depicts the variation in concrete mix density caused by the addition of steel mill scale. For all steel mill scale replacement levels, concrete density shows increased value than the control mix. The density of the control mix was 2134.85kg/m3 . On steel mill scales addition, gradual increase in concrete density was identified and reaches a maximum value of 2543.85kg/m3 at 100% replacement. The corresponding increase in density was around 20% for complete replacement of steel mill scale instead of sand.

The rough texture on surface of steel mill scale makes good binding with the cement mortar and produces a dense concrete. This increase in density of concrete is also attained because of the finer steel mill scale particles. This fine particle fills voids between conventional aggregates in concrete and hence the density of concrete increases obviously. The self-weight of concrete increases as the density of the concrete increases. This increase in self-weight is not very significant considering the benefits and savings obtained by this replacement.

Compressive Strength Test

Steel mill scale replacement (%)	Concrete's compressive Strength (MPa)
0	29.4
20	32.5
40	34.2
60	38.9
80	30.5
100	29.9

Split Tensile Strength

Steel mill scale replacement (%)	Split tensile strength of concrete (MPa)
0	3.6
20	4.03
40	4.22
60	4.53
80	3.82
100	3.63

Flexural Strength of Plain Cement Concrete

Steel mill scale replacement (%)	Flexural strength in concrete (MPa)
0	3.42
20	3.5
40	3.6
60	4.13
80	3.56
100	3.46

Ultra Sonic Pulse Velocity Test

Steel mill scale Replacement (%)	Cube size (in mm)	Velocity (km/s)	Quality
0	150 x 150 x 150	4.10	Good
20		4.16	Good
40		3.95	Good
60		4.73	Excellent
80		4.24	Good
100		4.16	Good

Load carrying capacity of beam

When a concrete beam is subjected to external loading it may fail due to shear stress or flexural stress. But shear reinforcements were provided in reinforced concrete beams to resist the shear stress and the beam fails only due to flexural cracks. Due to the application of load the beams starts bending, cracks form on its surface and the tensile reinforcement starts yielding. When the beam is loaded, further crushing of concrete occurs. Figure 4.9 represents the load carrying capacity of conventional RC beam and beams made with different percentage of steel mill scale. From the figure it was observed that load at first crack was approximately equals in all the substitution levels of steel mill scale. Simultaneously when the ultimate load at failure was taking into account the load carrying capacity of beams made with steel mill scale replacements were higher than the beam made with control mix. The ultimate load of conventional concrete was 70kN and that of concrete made with steel mill scale fine aggregate of 60% was 96.1kN which was 37.3% greater than control mix. The image confirms the optimum replacement level of 60% steel mill scale has increased load carrying capacity than all other concrete mixes. Concrete beams made with 80% and 100% steel mill scale replacement instead of revealed higher ultimate load carrying capacity than conventional concrete mix. This flexural strength increase is attained because of the presence in steel mill scale particles, the iron oxide which helps in increasing the deflection of beams before failure. Ultimate load carrying capacity of beam upsurges.

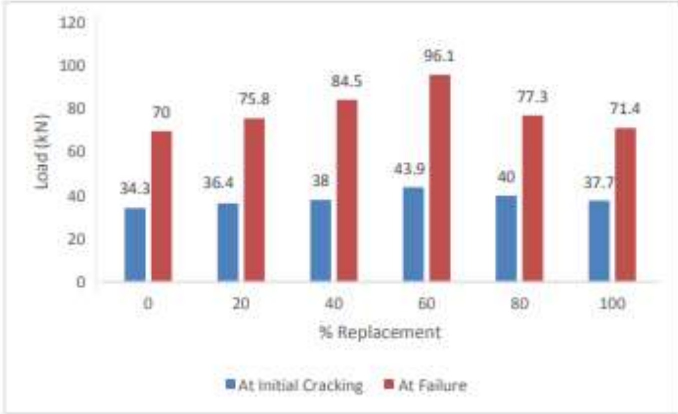
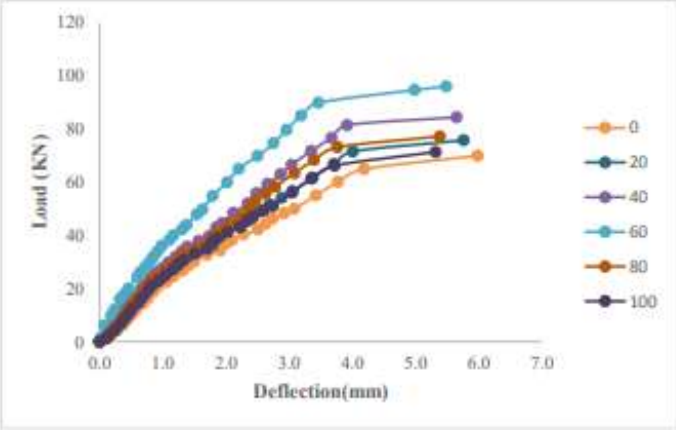
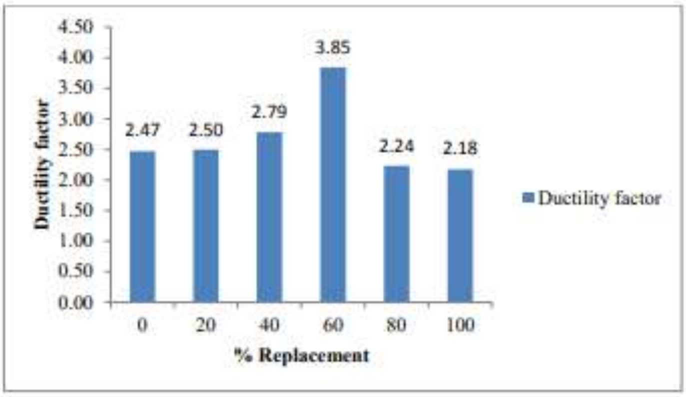


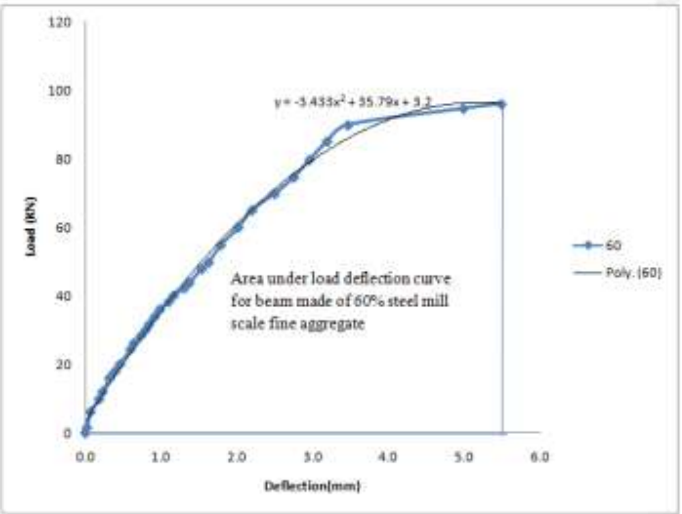
Figure 4.4 Load carrying capacity results of RC beams

Load Vs. Deflection behaviour

Deflection of beams means deformation of a beam from its original shape. Deflection study helps to understand the overall performance of a beam. When a simply supported beam is subjected to loading, its top fibre is subjected to compressive stress and bottom fibre is subjected to tensile stress and hence the beam tends to deflect downwards. Excessive deflection of beams causes spalling of concrete thus indicates beam failure. Figure 4.10 represents load deflection-curve for beams with different steel mill scale replacement levels. In all the cases the load deflection curves are steep and closely linear at initial stage. The slope of the curve changes because of flexural crack formation. The behaviour due to deflection of steel mill scale aggregate concrete was nearly similar to the deflection beams made of conventional fine aggregates. From the results it can make certainty that deflection of beam with steel mill scale of 60% is less compared to most of other beams, which indicates better ductility and capacity on deformation of the beam. Load deflection curves also represents that with steel mill scale addition, the capacity of energy absorption of beams increases.

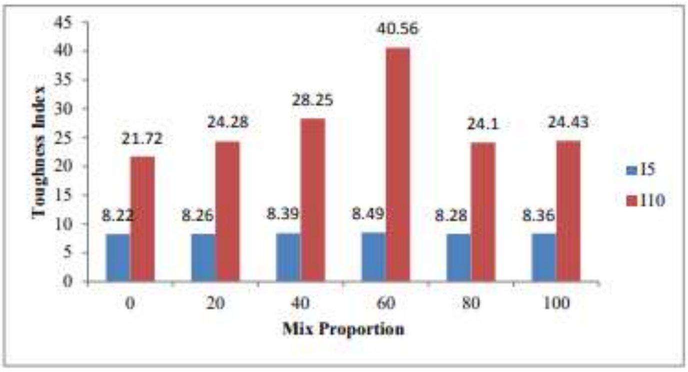






Steel mill scale replacement (%)	Energy Absorption Capacity (Area Under Load – Deflection Curve) in kN.mm
0	272.87
20	289.8
40	314.44
60	368.03
80	275.56
100	244.91

Steel mill scale replacement (%)	Toughness Index				
	Load - Deflection Area of first crack (P_A)	Load - Deflection curve Area of 3 times First Crack (Q_A)	Load - Deflection curve Area of 5.5 times First Crack (R_A)	Ratio I_5 = (Q_A)/ (P_A)	Ratio I_{10} = (R_A)/ (P_A)
0	7.56	62.12	164.185	8.22	21.72
20	7.63	63.03	185.29	8.26	24.28
40	7.54	63.275	213	8.39	28.25
60	6.485	55.06	263.05	8.49	40.56
80	8.23	68.12	198.37	8.28	24.10
100	7.43	62.132	181.52	8.36	24.43



Steel mill scale replacement (%)	Coulombs (Q)	Chloride ion permeability
0%	2837	Moderate
20%	2081	Moderate
40%	1753	Low
60%	998	Very low
80%	1227	Low
100%	1485	Low

Steel mill scale replacement (%)	% of weight loss	Compressive strength (90 Days) (MPa)
0%	0.0060	18.72
20%	0.0065	25.66
40%	0.0070	27.44
60%	0.0177	31.18
80%	0.0196	26.32
100%	0.0209	24.72

Test result shows that when river sand is replaced by steel mill scale, the loss in weight of concrete because of the action of sulphuric acid was decreasing. The initial weight loss of concrete at 0% replacement was 0.0060% and it was found 0.00177% for 60% replacement.

The Comparison of compressive strength before and after acid immersion. When the concrete specimen is subjected to sulphuric acid action, loss of weight in concrete is observed for specimens, which indicates the deterioration of the concrete mass. But, reduction in weight loss of concrete starts abruptly from 60% replacement ratio which having an ultimate compressive strength, whereas controlled specimen subjected to acid action, exhibits far lesser compressive strength.

Conclusion

It is concluded that use of steel mill scale in concrete is best suitable for all reinforced concrete structures, pavements, industrial structures and water tanks. Considering all the properties of steel mill scale inclusion in concrete viz. mechanical, workability, microstructural aspects, durability etc.., it is clearly evident from the results obtained from the experimental works that ultimate results are obtained at 60% replacement of steel mill scale. But, as the results obtained for 100% steel mill scale replaced specimens are higher and better than the specimens made with control mix, it is suggested to use the steel mill scale as a replacement for fine aggregates upto 100%. The durability performance of steel mill scale aggregates was significantly better than ordinary concrete so it can be used for normal environmental conditions. The findings of the experiment reveal that using steel mill scale in concrete minimizes the consumption of natural river sand while also solving its own disposal problem. As a result, steel mill scale can be used as an environmentally acceptable concrete material.

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