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STUDIES ON STRUCTURAL BEHAVIOUR OF CONCRETE WITH INDUSTRIAL WASTE

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ABSTRACT: Rapid urbanization in developing countries such as India is creating a shortage of adequate housing in cities. Using artificial aggregates for quality concrete is a natural step to mitigating this problem. The world wide consumption of materials in concrete production is very high, and several developing countries have encountered difficulties in meeting the supply of materials in order to satisfy the increasing needs of infrastructural development in recent years. Industrialization is one of the key factors for any developing economy like India. However, industrialization on the other hand has lead to serious problems leading to environmental pollution. Therefore, the industrial waste seems to be a by-product of the growth. The major generators of industrial solid wastes are the thermal power plants producing coal ash, the integrated Iron and Steel mills producing blast furnace slag and steel melting slag, non-ferrous industries like aluminium, zinc and copper producing red mud and tailings, sugar industries generating press mud, pulp and paper industries producing lime and fertilizer, allied industries producing gypsum, marble and stone cutting industry, textile industry generating solid sludge etc. The main idea of the present work is to examine the effect of adding waste foundry sand in the concrete mix. This work examines the possibility of using waste foundry sand as a partial replacement to sand for new concrete. Waste foundry sand was partially added to replace sand by 0%, 10%, 20%, 30%, 40%, 50% and tested for its compressive, Split Tensile and flexural strength at 28 days, and were compared with those of conventional concrete. From the results obtained, it reveals that compressive strength flexural strength and split tensile strength of the conventional concrete are very close to the concrete with waste foundry sand up to 20% replacement. However beyond 20% replacement of sand with waste foundry sand, the strengths were found to decrease.
KEYWORDS: Waste foundry sand, Admixture, Compressive Strength, Flexural Strength, Split tensile Strength.

I. INTRODUCTION

The rapid advance of globalization and the growth in the population has resulted in a growth in building construction that has consequently led to a higher demand for construction materials. Concrete is the most widely used construction material in the construction industry, and offers a number of advantages, including good mechanical and durability properties, low cost, and high rigidity. River sand is one of the main ingredients used as a fine aggregate in concrete production. In recent years, the construction industry has been faced with a decline in the availability of natural sand due to the growth of the industry. On the other hand, the metal casting industries are being forced to find ways to safely dispose of waste foundry sand (FS). With the aim of resolving both of these issues, an investigation was carried out on the reuse of waste FS as an alternative material to natural sand in concrete production, satisfied with relevant international standards.

FINE AGGREGATE

Sand is a significant material utilised for the composition of mortar and concrete and assumes a most essential part in design mix. Sand is a major component of concrete and properties of a specific concrete mix will be determined by the proportion and type of sand used to formulate concrete. It has significant impact on the workability, durability, strength, weight, and shrinkage of concrete. Sand is usually a larger component of the mix than cement. Sand can fill up the pores or voids in the concrete, which is also a contributing factor for the strength of concrete. Sand reduces volume changes resulting from setting and hardening process and provides a mass of particles which are suitable to resist the action of applied loads and show better durability than cement paste alone. Hence sand has a major role for concrete to solidify to give the necessary strength. Use of regular sand is high, because of the large utilisation of mortar and concrete. Thus the need of sand is more in growing countries to mitigate the fast infrastructure development. The growing demand of sand results in non-availability of good quality sand and especially in India, deposits of natural sand are being exhausted which create an extreme menace to the environment. Fast withdrawal of sand from waterway bed, brings about such a large number of issues like losing water holding soil strata, extending to the sliding of the banks of river . The extraction of sand from the waterway enhances the cost of sand and has severely affected the financial viability of the construction industry. As such finding an alternate material to natural sand has got to be imperative. As the industrialisation increases, the amount of waste material product is also increasing, which has turned into an ecological issue that must be managed. Pappu et al. (2007) stated that in India 960MT solid waste is being generated yearly, out of which 290MT are unwanted inorganic waste of mining & industrial division. Regular resources are exhausting largely while in the meantime the produced wastes from the industries are expanding significantly. To safeguard the environment, efforts are being made for using industrial waste in concrete for conserving natural resources and reduce the cost of construction materials. Assuming industrial waste in the form of fine aggregate for concrete production can be considered one of the environmental benefits and also shows better performance in concrete. The utilisation of waste items in concrete makes it inexpensive and reutilize of wastes is supposed as the best ecological option for taking care of the issue of waste disposal. A rising demand for construction material has led to the overexploitation of river sand, and this overexploitation has led to harmful consequences like increase in river bed depth, lowering of the water table, and intrusion of salinity into the river. In addition, the restriction in the extraction of sand by government organizations has increased the price of sand, severely affecting the stability of the construction industry. For this reason, finding an alternative material to sand has become vital. Over the last several decades, an enormous amount of research has been carried on the use of industrial waste, including granite and marble waste , tire waste , palm oil ash , timber waste , and also marine sand as a substitute/replacement material for fine aggregate. From the research outcomes, it was suggested that the substitution of industrial waste as an alternative material in concrete making could improve the structural properties of concrete and promote sustainable concrete development.

WASTE FOUNDRY SAND (WFS)

Foundry sand (FS) is a high silica content sand material which is a by-product from the metal alloys casting industries. In foundries, superior silica sands are bonded with clay or chemicals and used for the material moulding and casting process. Foundries recycle the sand as many times as possible, and when the sand is no longer recyclable, then it is disposed of; this is called foundry sand. About 15% of the sand utilized in casting production is ultimately disposed of by the foundry industry, amounting to millions of tons. In India, many foundry industries are dumping this waste in nearby vacant areas, which is creating an environmental problem. In Coimbatore, Tamilnadu, India, many residential areas are established over landfills, which are basically composed of FS from ferrous and nonferrous industries. Landfill is an incorrect option, because the embodied energy in FS is not used and will create soil contamination. Over the last several decades, FS has been reused as a subgrade material in highway and soil stabilization application . However, the waste that is reutilized in this way very is negligible, and the practice presents the risk of leaching intrusion. Very recently, research has been carried out on the reutilization of FS as substitute material in concrete and concrete related products. A marginal increase in the strength properties can be achieved by the inclusion of UFS as partial replacement for fine aggregate in concrete making . The replacement of 10% aggregates with waste foundry sand was suitable for asphalt concrete mixtures, and the substitution did not significantly affect the environment around the deposition . FS is a viable means of producing economical self-compacting concrete (SCC) by using FS substitution; however, further research is needed to develop the optimum FS proportion .The substitution of foundry sand in concrete reduces the voids in concrete and has helped to spread the C–S–H gel widely in the concrete . The Inclusion of FS as a sand replacement significantly improved the abrasion resistance of concrete at all ages because of the formation of a denser matrix. FS can be effectively utilized in making good quality RMC as a partial replacement for fine aggregates with no adverse mechanical, environmental, and microstructural impacts; however, the replacement should not exceed 20%. It can be understood that a great deal of research has been carried out on the reuse of FS in civil engineering application. However, limited research has been focused on the use of FS in concrete production, and more research is also needed to develop the most favorable replacement of FS in concrete production. With this aim, the main objective of this experimental investigation is to examine the potential reuse of FS obtained from an aluminium casting industry, Coimbatore, in Tamilnadu, India, as a replacement for fine aggregate in concrete production, at different substitution rates. The effect of FS substitution on the mechanical properties of concrete was examined. In addition, the influence of FS on the durability properties of concrete was also evaluated in order to ensure the reliability of its usage in aggressive environments. Based on the results of the mechanical and durability tests, the most favourable proportion of FS in concrete production was established.

Figure 1 View of Waste Foundry Sand

OBJECTIVE OF THE PRESENT WORK:

The basic objective of this study is to identify alternative source of good-quality aggregates, which is depleting very fast due to the fast pace of construction activities in India. Use of Waste Foundry Sand (WFS), an industrial by-product of foundries provides great opportunity to utilize as an alternative to normally available aggregates. In the present work, an experimental study was carried out to investigate the applicability of waste foundry sand as a partial replacement of sand in concrete. Fresh and hardened properties of the WFS mixed concrete were estimated and conclusions were presented.

II. MATERIALS

CEMENT: For the present experimental investigation work OPC 53 grade cement is used whose properties are given in the following table.

Table 1 Physical properties of Cement

S.NO	PROPERTY	VALUES
1	Fineness of Cement(in specific surface)	225 m^2/kg
2	Specific Gravity	3.1
3	Normal Consistency	33 %
4	Initial Setting time Final setting time	45 mins 6 hours
5	Compressive Strength in 3days Compressive Strength in 7days Compressive Strength in 28days	32 N/mm^2 46 N/mm^2 58 N/mm^2

AGGREGATES

Machine Crushed granite aggregate confirming to IS 383-1970 consisting 20 mm maximum size of aggregate has been obtained from the local quarry. Coarse aggregates are shown in figure 3.2. It has been tested for Physical and Mechanical Properties such as Specific Gravity, SieveAnalysis, Density values and the results are as follows.

- Specific Gravity coarse aggregate is 2.61
- Fully compacted density of coarse aggregate is 1690kg/m3
- Partially compacted density of coarse aggregate is 1466kg/m3
- Fineness Modulus of Coarse Aggregate 9.09

Table 2 Physical properties of Coarse Agregate

S.NO	PROPERTY	VALUES
1	Specific Gravity	2.75
2	Bulk Density Loose State Compacted State	14.13 kN/m^3 16.88 kN/m^3
3	Water Absorption	0.7%
4	Flakiness Index	14.22%
5	Elongation Index	21.33%
6	Crushing Value	21.43%
7	Impact Value	15.5%
8	Fineness Modulus	3.4

WASTE FOUNDRY SAND

Waste Foundry Sand was procured from the nearby aluminium casing foundry industry. The physical and chemical properties of the waste foundry sand were given in the following tables:

Table 3 Physical Properties of WFS

Physical Properties	Waste Foundry sand
Specific gravity	2.24
Density (kg/m3)	1576
Water absorption (%)	1.13
Materials finer than 75 μm	8

Table 4 Chemical composition of WFS

Chemical composition	Waste Foundry sand
	%bymass
Lime (as CaO)	0.22
Soluble silica (as SiO2)	87.48
Alumina (as Al2O3)	4.93
Iron oxide (as Fe2O3)	1.31
Magnesia (as MgO)	0.18
Sulphur calculated as sulphuric anhydride (as SO3)	0.07
Loss on ignition (LOI)	5.81

III. METHODOLOGY

CONCRETE MIX PROPORTIONS

Concrete mix proportions were designed to achieve the strength of M25, according to IS 10262:2009. The concrete mix proportion was 1 : 1.53 : 2.86. A constant water to cement ratio (W/C) was followed for all mixtures, and the value was about 0.44. Of the six mixtures, five mixtures were prepared by replacing 10%, 20%, 30%, 40%, and 50% of natural sand with FS, and the one remaining mixture was a control mixture (CM) that did not use FS.

The detailed formulation of the proportions of six mixtures was given in Table 5 below:

Table 5 Mix Proportions of ingredients(for M-25)

MIXTURE DESIGNATION	% WFS ADDED	WATER (KG/M^3)	CEMENT (KG/M^3)	SAND (KG/M^3)	COURSE AGGREGATE (KG/M^3)	WASTE FOUNDRY SAND (KG/M^3)
WFS0 (CM)	0	177	402.37	616.52	1152.25	0
WFS10	10	177	402.37	554.86	1152.25	61.65
WFS20	20	177	402.37	493.26	1152.25	123.30
WFS30	30	177	402.37	431.56	1152.25	184.96
WFS40	40	177	402.37	369.91	1152.25	246.61
WFS50	50	177	402.37	308.26	1152.25	308.26

PREPARATION OF CONCRETE SAMPLES

Concrete cubes of size 150×150×150mm, cylinders of size 300x 150 and beams of size 700x150x150mm were casted in standard moulds at three intervals (around 50 mm each). At each interval, concrete was compacted giving 25 blows by a compaction rod. At the end of the third interval, cubes and beams were vibrated for 1-2 minutes on a vibrating machine and then the top surface of the cube was finished using a trowel. After that, the moulds were left for drying for 24 hours. At the end of 24 hours, the cubes and beams were removed from the moulds and were submerged in water tanks for curing for 28 days.

TESTING OF SPECIMENS

Cube compressive strength test:

Compression test on the cubes is conducted on the 2000 kN AIMIL - make digital compression testing machine. The pressure gauge of the machine indicating the load has a least count of 1 kN. The cube was placed in the compression-testing machine and the load on the cube is applied at a constant rate up to the failure of the specimen and the ultimate load is noted. The cube compressive strength of the concrete mix is then computed. This test has been carried out on cube specimens at 28 days age.

Split tensile strength test:

This test is conducted on 1000 kN AIMIL make digital compression testing machine. The cylinders prepared for testing are 150 mm in diameter and 300 mm long. After noting the weight of the cylinder, diametrical lines are drawn on the two ends, such that they are in the same axial plane. Then the cylinder is placed on the bottom compression plate of the testing machine and is aligned such that the lines marked on the ends of the specimen are vertical. Then the top compression plate is brought into contact at the top of the cylinder. The load is applied at uniform rate, until the cylinder fails and the load is recorded. From this load, the splitting tensile strength is calculated for each specimen. In the present work, this test has been conducted on cylinder specimens after 28 days.

Flexural strength test:

The test is conducted on a loading frame. The beam element is simply supported on two rollers of 4.5 cm diameter over a span of 450 mm. The element is checked for its alignment longitudinally and adjusted if necessary. Required packing is provided using rubber material. Care was taken to ensure that the two loading points were at the same level. The loading was applied on the specimen through hydraulic jacks and was measured using a 500 kN pre-calibrated proving ring. The load is transmitted to the beam element through the I-section and two 16mm diameter rods spaced at a distance of 300mm. For each increment of loading, the deflections at the centre of span are recorded using dial gauges. Continuous observations were made and the cracks were identified with the help of magnifying glass. Well before the ultimate stage, the deflectometers were removed and the process of load application was continued. As the load increased, the cracks are widened and extended to top and finally the specimen collapsed in flexure.

IV. RESULTS AND DISCUSSIONS

The test results for workability, compressive strength of concrete cubes split tensile strength of cylinders and flexural strength of concrete beams were presented in tabular forms and graphs.

WORKABILITY

The slump cone test was used to measure the workability of the concrete with the time ranging from 0 min, 30 min and 60 min. The influence of the FS on the workability is presented in Table 6 and Fig. 2.

Table. 6 Workability test results

MIXTURE DESIGNATION	% WFS ADDED	WORKABILITY (SLUMP IN MM)
WFS0(CM)	0	116
WFS10	10	113
WFS20	20	100
WFS30	30	93
WFS40	40	75
WFS50	50	64

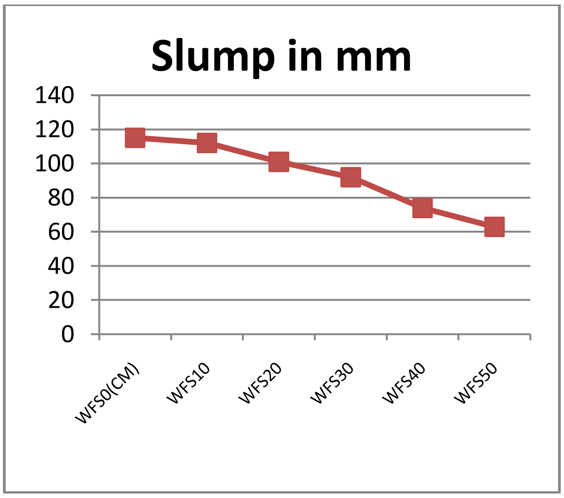

Figure 2. Influence of WFS on Workability of concrete

However, the effect of FS on workability is not significant with the substitution rate up to 10%, and the slump value of the mixtures was relatively equal to the CM. However, beyond the 10% substitution rate a loss in the workability of the concrete was observed. We know that the workability of concrete is directly proportional to the fineness of the material used in concrete.

COMPRESSIVE STRENGTH

The compressive strength of all mixtures at the age 28 days are given in Table 4.2 and are presented in Fig. 4.2. The aim of this investigation is to reuse the FS in concrete production without affecting the limitations described in the concrete standards. The test results revealed that FS can be effectively used as a substitute material for fine aggregate in concrete production. Even though no marginal improvement in strength was observed the compressive strength of the concrete mixtures containing FS up to 20% was relatively close to the strength of the CM. Compared to mixtures FS 20% and FS 30%, the mixtures CM showed a increased compressive strength of only 1.6% and 5.7%, respectively, at the age of 28 days, which is not significantly different from the strength value of CM. However, mixtures FS 40% and FS 50% showed lower strength when compared to the CM, and the mixtures showed a decrease in compressive strength of 11.04% and 23.95% compared to CM at the age of 28 days.

Table 7 Compressive Strength with replacement of WFS for 28 days, MPa

MIXTURE DESIGN -ATION	% WFS ADDED	COMPRESSIVE STRENGTH - 28DAYS (N/MM^2)
WFS0(CM)	0	33.16
WFS10	10	33.22
WFS20	20	32.56
WFS30	30	31.22
WFS40	40	29.46
WFS50	50	25.21

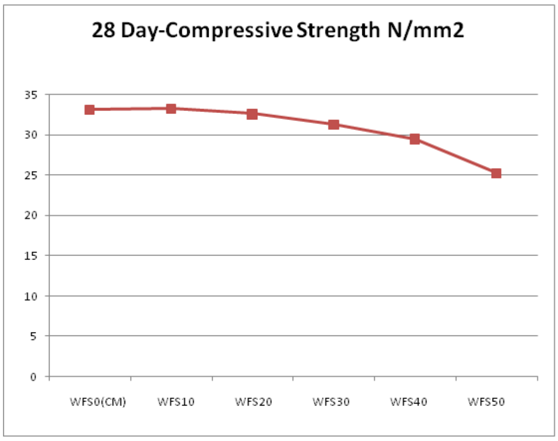

Figure 3 Compressive strength for 28 days

FLEXURAL STRENGTH

The 28, days average flexural strength of all concrete mixtures are listed in Table 4.3 and are presented in Fig. 4.3. Like compressive strength, the flexural strength of the concrete mixtures up to a 20% substitution rate was comparatively equal to the flexural strength of the CM. However, the flexural strength of the concrete started to decrease significantly when the substitution rate became higher than 20%. The flexural strength of the control mixture was 4.087 N/mm2 at the age of 28 days, whereas the mixtures FS 10%, FS 20% and FS 30% achieved strengths of 3.986, 3.988 and 3.879 N/mm2, respectively, which was only 2.47%, 2.42% and 5.08%, respectively, lower than the strength of CM. The flexural strength of all concrete mixtures was increased upon aging; however, the enhancement in the strength was poor beyond the substitution rate of 20% (for FS 40% and FS 50%). Based on this observation, it can be concluded that the strength properties of the FS concreteagreed with the standards, and it is suggested that FS can be effectively used as a fine aggregate with the maximum substitution rate of 20% in concrete making.

Table 8 Flexural Strength with replacement of Cast iron turning for 28 days, MPa

MIXTURE DESIGNATION	% WFS ADDED	FLEXURAL STRENGTH – 28DAYS (N/MM^2)
WFS0(CM)	0	4.06
WFS10	10	3.98
WFS20	20	3.96
WFS30	30	3.86
WFS40	40	3.66
WFS50	50	3.64

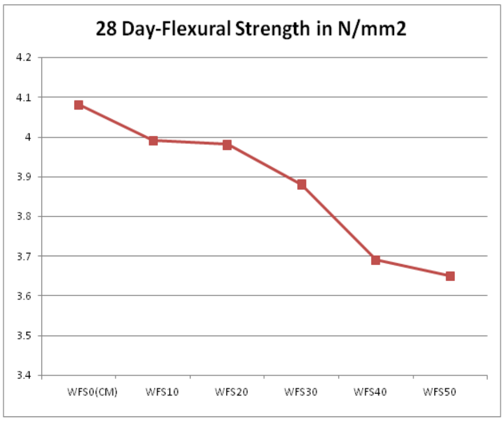

Figure 4 Flexural strength for 28 days

SPLIT TENSILE STRENGTH

Splitting tensile strength of the concrete was determined at the ages of 28 days, and the results are summarized in Table 4.4 and presented in Fig. 4.4. The results obtained revealed that the tensile strength of the concrete decreased with the increase in the FS substitution rate; however, the tensile strength values of the mixtures with the substitution rate of 20%, are approximately equal to the strength of CM. At the age of 28 days, compared to CM, the decrease in tensile strength of the concrete mixtures FS 10%, FS 20% and FS 30% was 4.53%, 6.03% and 7.08%, respectively, and this difference in strength is not relatively high. However, the obtained tensile strength of the concrete mixtures FS 40% and FS 50% was shown to be very poor when compared to the CM observed at the all ages of concrete, and the mixtures showed tensile strength that was decreased by 16.38% and 19.32%, respectively.

Table 9 Split tensile Strength with replacement of Cast iron turning for 28 days, MPa

MIXTURE DESIGNATION	% WFS ADDED	SPLIT TENSILE STRENGTH - 28DAYS (N/MM^2)
WFS0(CM)	0	2.74
WFS10	10	2.60

WFS20	20	2.58
WFS30	30	2.50
WFS40	40	2.30
WFS50	50	2.20

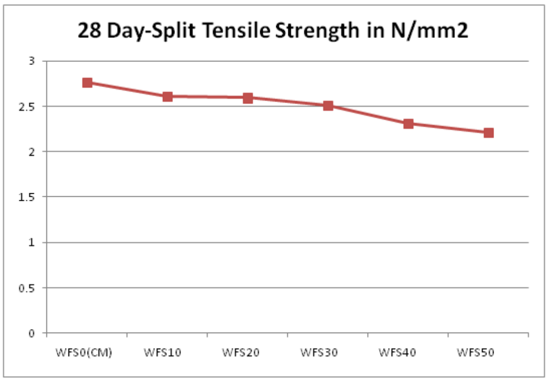

Figure 5 Split tensile strength for 28 days

V. CONCLUSIONS

Based on the test carried out on the five mixtures the following conclusions have been made:

- Workability of the concrete decreases with an increase in the FS substitution rate.
- The fineness and high water absorption properties of the FS reduce the workability of the concrete.
- The strength properties of the concrete mixtures containing FS up to 20% was relatively close to the strength value of the CM.
- The concrete mixtures with WFS 20% and WFS 30% showed a decrease in compressive strength of only 1.81% and 5.85%, respectively, at the age of 28 days when compared to the CM which is very marginal.
- The flexural strength of the control mixture was 4.06 N/mm^2 at the age of 28 days,
- whereas the mixtures WFS 10%, WFS 20% and WFS 30% achieved strengths of 3.98, 3.96 and 3.86 N/mm2, respectively, whichis only 1.97%, 2.46% and 4.92%, respectively lower than the strength of CM.
- Beyond the substitution rate of 20% the concrete mixtures showed inferior behavior when compared to the CM due to fineness of FS and the presence of clay, sawdust and wood flour in the FS.
- From the results obtained it is suggested that FS with a substitution rate up to 20% can be used effectively as a fine aggregate in good concrete production without affecting the concrete standards.

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