UTILIZATION OF WASTE FOUNDRY SAND IN CONCRETE PAVER BLOCKS

A

THESIS

Submitted in partial fulfillment of the requirements for the award of the degree

of

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With specialization in

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Under the supervision

of

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May-2020

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"UTILIZATION OF WASTE FOUNDRY SAND IN CONCRETE PAVER BLOCKS"** submitted for partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Pankaj Kumar**, **Assistant Professor and Mr. Abhilash Shukla**, **Assistant Professor**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"UTILIZATION OF WASTE FOUNDRY SAND IN CONCRETE PAVER BLOCKS "** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Civil Engineering with specialization in "Structural Engineering" and submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Atish Bhardwaj (182658)** during a period from July, 2019 to May, 2020 under the supervision of **Mr. Pankaj Kumar and Mr. Abhilash Shukla**, **Assistant Professor**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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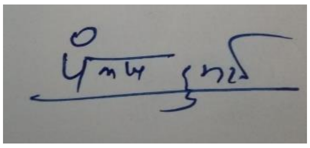

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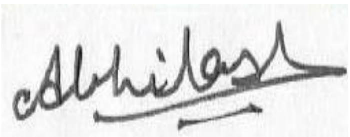

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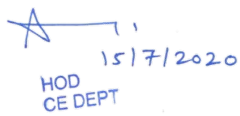

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ABSTRACT

The need of concrete is increasing every year as the population of humans are increasing as per their demands i.e. infrastructure developments and shifting composition etc. Due to rising demands and fight to produce good quality of concrete, construction industries have overused the natural materials used in concrete, leads us to extinction in natural materials and results in rising prices of materials. Thus, the environmental problems related with excessive extraction and mining from natural sources have been reported in many countries. Due to finite availability of natural materials, and involvement of economy, it has now become very important to look as for the alternative source for natural materials used in concrete i.e. gravels and natural sand. Waste foundry sand (WFS) is a propitious material that can be used as an alternative for the natural sand i.e. (fine aggregates) in concrete. The thesis demonstrates the potential of re-use for waste foundry sand i.e. industrial by-product as a substitute of a fine aggregate in concrete. The fine aggregates i.e. (natural sand) are replaced with WFS in six different substitution rates i.e. (2.5%, 5%, 7.5%, 10%, 12.5% and 15%). Several tests were performed to examine the mechanical properties i.e. (compressive strength, flexural strength and splitting tensile strength) as well as the durability of concrete i.e. (sulphate resistance). The results indicate that the compressive strength was increased from 3.93%–9.3%, splitting tensile strength increased from 4.8%-11.37%, flexural strength increased from 3.81% -12.27% for 2.5%-5% replacement levels of waste foundry sand with fine aggregates in concrete and after that there is a systematic decrement in strength as the percentage goes on increasing at curing age of 28 days. The strength in Sulphate resistance test was increased up to percentage level of 10% with natural sand as a fine aggregate in concrete and after that there is a systematic decrement in strength. From following results, it was concluded that 10% WFS replacement level of WFS with fine aggregate in concrete can be effectively used to make concrete and various application of concrete i.e. (concrete paver blocks) and beyond 10% WFS replacement level is not beneficial.

Keywords: Waste foundry sand, materials, concrete, natural sand

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LIST OF ACRONYMS AND ABBREVIATIONS

WFS	Waste foundry sand
MSMEs	Ministry of micro, Small, and Medium
CLSM	controlled low-strength material
BA	Bottom ash
FA	Fly ash
SCC	Self-compacting concrete
RCS	Residue of compressive strength
C-H-S	Calcium-Silica-Hydrate
PPC	Portland pozzolana cement
W/C	Water cement ratio

CHAPTER 1
INTRODUCTION

1.1 General

Concrete is the backbone of construction industries around the world. The need of concrete is increasing day by day as the population of humans are increasing as per their demands i.e. infrastructure developments and shifting composition etc. The primary constituents of concrete like cement, sand and coarse aggregates are depleting as the demand of concrete is rising around the world and leads us to various sustainable issues. Globally, production of cement in China was 2.4 billion tons, in USA was 86.63 million tons and in India was 270 million tons in 2017 year. In the USA, every 1 ton of cement requires 10 tons of aggregates to produce concrete[1].In the production of concrete, aggregates makes its volume of 70% as the principal of component material and industries of concrete globally consumes 8 to 12 million tons of aggregates annually after 2010 year[2]–[4].

Increasing population in the world every year, results in the raising the demand for construction materials and this will lead us to shortage in materials, rising prices and negatively affecting the environment in future. As a report published by UNEP February[1], composition of concrete is 25% of fine aggregates, 45% of coarse aggregates, 10% of cement, 18.5% of water and 1.5% of air, and this shows that aggregates are the most essential material for construction industries and 75% of aggregates are used to produce concrete. As per composition of concrete fine aggregates and coarse aggregates are the major ingredients i.e. crushed rocks, natural sand and gravels and reported that 40-50 billion metric ton of these materials are extracted from coastlines, sand near river site and quarry pits the marine environment every year[1]. Globally, an extraction of material from environment is estimated from 47 billion to 59 billion construction tons[5], of which sand and gravels used as a fine aggregates and coarse aggregates in concrete accounted as the largest share in extraction i.e. from 68%-85%[6],[7].

Surprisingly, natural sand as a fine aggregate and gravels as a coarse aggregate in concrete are mined more as compared to other construction material. These raw materials are struggling to cope with increasing demands in many places and areas around the world. Now a days, excess use of concrete give rise to the environmental issues and the sources of great quality of river sand and gravels are rapidly depleting. These materials cannot be extracted from environment in large quantity and used without a negative and serious impact on the environment. Due to rising demands and fight to produce good quality of concrete, construction industries have overused the natural materials used in concrete leads us to extinction in natural materials and results in rising prices of materials[8]. Thus, the environmental problems related with excessive extraction and mining from natural sources have been reported in various locations of Asia, Africa and south America[9]. India and China are listed at the top most country as a hotspot for extraction sand from rivers, coastlines and lakes[10], these countries moreover also lead on the field of infrastructures and infrastructures. Therefore, excessive extraction and mining causes change in PH level, affect the river ecosystem and has led to threaten the number of locations in the world. By seeing these certain fact government of the various countries have banned sand mining and extraction of sand from natural sources which leads now to look for the alternative source of natural sand.

1.2 Alternative for Natural Sand (fine aggregates)

As the natural sand supplies from the natural sources are near the point of becoming exhausted, this ultimately leads in increasing the cost of natural sand. The sustainable growth in construction world in modern times for fulfilling the demand of sand is needed as alternative source that should be abundantly available and satisfy all required technical specification for fine aggregated. A lot of research during the past few decades have been conducted to find an alternative source for a fine aggregate (natural sand) [11]–[16].

Now a days, with ongoing various research and development in construction field, researchers found that several waste materials have almost similar properties as compared to fine aggregates. WFS is a by-product for metal casting industries and carries almost similar properties as compare to sand. Waste foundry sand suitably used and recycled various times for casting and moulding operation, and further when recycled sand can no longer be reused in these operations are expelled from the casting industries. The production of waste foundry sand in large amount from industries is also a problem issues for reusing it in a beneficial way. Due to production of WFS in large volume around the world and contains silica content in large amount it attracts interests of lots of government bodies and researchers.

Use of industrial by-product in a serious manner drawn attention of researchers and these by-products has investigated by researchers and industries for several years as a partial and full replacement of waste materials with fine aggregates in concrete. Siddique[17] gave an overview for the utilization of several industrial waste materials as a partial replacement with natural sand in concrete i.e. dust of cement kiln, wood ash, WFS, and coal bottom ash. and furthermore, also discussed chemical, physical and mineralogical properties of these wastes. Dash et al.[4] published an article of review based on utilization of various products and by-products waste of industries i.e. copper slag, palm oil clinker, coal bottom ash, ferrochrome slag, steel slag, waste foundry sand and imperial smelting furnace slag etc. Each waste product has a different and unique effect on various properties of concrete.

1.3 Foundry Sand

The foundries are originated from the region of Mesopotamia and from Iraq and Syria. Fire pits and casting of clay worked to make shapes of silver, copper and gold[18]. The shape of WFS is sub-angular to round suitably, and it has an immense thermal conductivity which is helpful in using it for casting and moulding operations. The foundry sand contains bentonite clay presents in very less amount and it also acts as binder material. Furthermore, foundry sand also contains chemical binders which acts to create sand cores. Foundry sand is used and recycled various times in metal casting industries for mouldings and casting operations to a certain point where it can no longer be reused and when it is no longer be reused is expelled from the operation, and the new sand is introduced and imported to this cycle. Then, the expelled sand from the casting operations and foundries is known as WFS. WFS is a by-product of metal casting industries i.e. (ferrous and non-ferrous) which contain silica in high amount.

In metal casting industries, waste foundry sand (WFS) is mainly characterized on the basis of binders and binder's system. Green sand and chemically bonded sand are the sand used in casting process.

Green sand (clay bonded sand) is a mixture of silica sand from (80%-95%), bentonite clay from (4%-10%), carbonaceous addictive from (2%-10%) and water from (2%-5%) and used in various type of mould making processes. Other several ingredients contained by these types of sand is rice hulls, flour, starches and cereals. Presence of silica in high amount in green sand used to resist very immense temperature and presence of bentonite clay combine the clay, whereas presence of water acts to activate the system of bentonite clay. Furthermore, presence of minor ingredients improves the fluidity and these ingredients also absorbs the moisture. Magnesium oxide, titanium dioxide, and potassium dioxide are some of the chemicals which are also presents in green sand. In the iron world of casting, 85% of green sand is used in the operation of moulding. The green sand is called green in colour due to presence of akin to green wood in a wet stage, however it is not green.

Chemically bonded sand is generally use for both the operations like core making and moulding. This sand is a mixture of 1%-3% of chemical binders and also contains very high amount of silica. Silica in very high amount is required to resist temperature that is needed for core making processes. There is various chemical binder that are used in this sand by foundries industries i.e. urethane (phenolic), phosphate, furfuryl alcohol, sodium silicate, flake resins, phenolic resole-ester phenolic no bake-acid and alkyd (oil) urethane. The chemical bounded sand that are most commonly used in foundries are cold box, Co_2 sand, hot box and resins coated sands. The various binders and binder's system used in foundries are phenolic no-bake, epoxy So_2 , alkyd oil- Sodium silicate, phenolic no-bake, phenolic esters, phenolic urethanes, Sulphur dioxide, furan no bake, based on core oil, furan warm box , alkyd oil- Sodium silicate and alkyd urethane use in sand moulding processes. As compare to green sand this sand is light in colour.

1.4 Properties of Foundry Sand

The major component of foundry sand is silica which is present in high amount in foundry sand and this component is also present in natural sand but in lower amount as compare to foundry sand. The physical properties, chemical properties and mechanical properties of waste foundry sand depends and can vary due to many factors i.e. Different places and industries from which it originates, types of addictive added during casting operations, types of binder and binder's system used, several times sand is recycled for moulding and types of addictive used during moulding operations[19].

1.4.1 Physical Properties

WFS contain silica in high amount which as compare to regular sand is high but size of WFS is very less as compared to regular sand and presence of several addictive and binders can affect the physical properties of WFS. There are following physical properties given below.

a) According to ASTM C33[20], Particle shape of waste foundry sand is typically subangular to rounded.
b) 85% to 95% of waste foundry sand is ranging between sieves of 0.6 and 0.15 mm[21].
c) 5%-12 % of WFS can pass through or is smaller than 0.075 mm sieve[21].
d) It is non plastic and has low absorption.
e) As reported that the values of water absorption vary widely of WFS as compared to regular sand.
f) The value varies from 2.39 to 2.35 of specific gravity for WFS[22].
g) The WFS contains waste material i.e. core and metal material and it also carries partially degraded binders.
h) Several foundries use in various places uses various binder i.e. sawdust, clay and flour which results in decrease in the specific density and this causes decrease in density of concrete.

Table 1.1 Physical properties of WFS reported by various researchers

Physical properties	Singh & Siddique [23]	Siddique et al. [24]	Naik et al. [25]	Guney et al. [26]	Naik et al. [27]	Prabhu et al. [28]
Specific gravity	2.18	2.61	2.79	2.45	1.97	2.24
Density (kg/m^3)	-----	1638	1784	-----	1538	1576
Fineness modulus	1.89	1.78	2.32	-----	1.32	-----
Water absorption (%)	0.42	1.3	5	-----	3.2	1.13
Particle below 75µm (%)	8	18	1.08	24	54.9	8
Moisture content (%)	0.11	-----	-----	3.25	-----	-----
Clay lumps and finable particles	0.8	0.9	0.4	-----	-----	-----

Many researchers during the past few decades have conducted researches about the various properties of WFS and found that WFS has almost similar results as compare to regular sand. Table no.1 shows the various physical properties of WFS reported by various researchers.

1.4.2 Chemical Properties

Waste foundry sand contain silica in high amount which as compare to regular sand is high but size of WFS is very less as compared to regular sand and presence of several addictive, binders and types of metals used can affect the chemical properties of WFS. There are following chemical properties given below.

a) The WFS is hydrophilic in nature because it contains silica in high amount and could lead to attract water to its surface[29],[30].

b) It is coated with a film which is thin with burnt carbon, residue binders i.e. chemicals or resins or sea-coals and contain dust[31].
c) Depending on the types of metals used and binders used in it, the value for pH of WFS can vary from 4 to 8.
d) Some of WFS are reported because of presence of corrosive metals in it.
e) X-ray diffraction was done on was foundry sand i.e. lesser that (75 µm)[32].

Table 1.2 Chemical characterization of WFS obtained from various sources

Constituents	**American Foundry Society**[30]	**Basar et al.** [33]	**Singh & Siddique** [34]	**Prabhu et al.** [35]	**Thaarrini et al.** [36]
SiO_2	87.91	81.85	83.8	87.48	83.93
$Al_2 O_3$	4.7	10.41	0.81	4.92	0.21
$Fe_2 O_3$	0.94	1.82	5.39	1.31	0.95
CaO	0.14	1.21	1.42	0.22	1.03
MgO	0.3	1.97	0.86	0.18	1.77
SO_3	0.09	0.84	0.21	0.07	0.057
MnO	-----	-----	0.047	-----	-----
TiO_2	0.15	-----	0.22	-----	-----
$K_2 O$	0.25	0.494	1.14	-----	-----
$P_2 O_5$	-----	-----	-----	-----	-----
$Na_2 O$	0.19	0.764	0.87	-----	-----
LOI	5.15	6.93	-----	5.81	2.19

Many researchers during the past few decades have conducted researches about the various properties of WFS and found that WFS has almost similar results as compare to regular sand. Table no.2 shows the various chemical properties of WFS reported by various researchers.

1.4.3 Mechanical Properties

Waste foundry sand contain silica in high amount which as compare to regular sand is high but size of WFS is very less as compared to regular sand and presence of several addictive, binders and types of metals used can affect the Mechanical properties of waste foundry sand. For examination of mechanical properties various tests were performed, and the tests shown good results of durability as well as overall report. The abrasion was reported below 2% and soundness loss was reported within 5% to 15%[39]. The WFS internal friction angle was reported equal to shearing resistance of regular or natural sand i.e. ranging between 33° and 40° [39].

1.5 Production

1.5.1 The Global Scenario

From 3000 foundries, United States utilizes annually about sand for 100 million tons are used in foundries and per year about (6 to 10) million metric tons is discarded as WFS, which is used in landfills [40],[39]. As per 53rd world casting census production[41], the total global casting production in the world increased up to 112.7 million metric tons as compared to 2018 year there is an increase of 2.6% in 2019 year. China, India and USA holds the top three positions in world casting census production and in India there is an increase of 11% of casting production in 2019 year as compared to previous year[41].

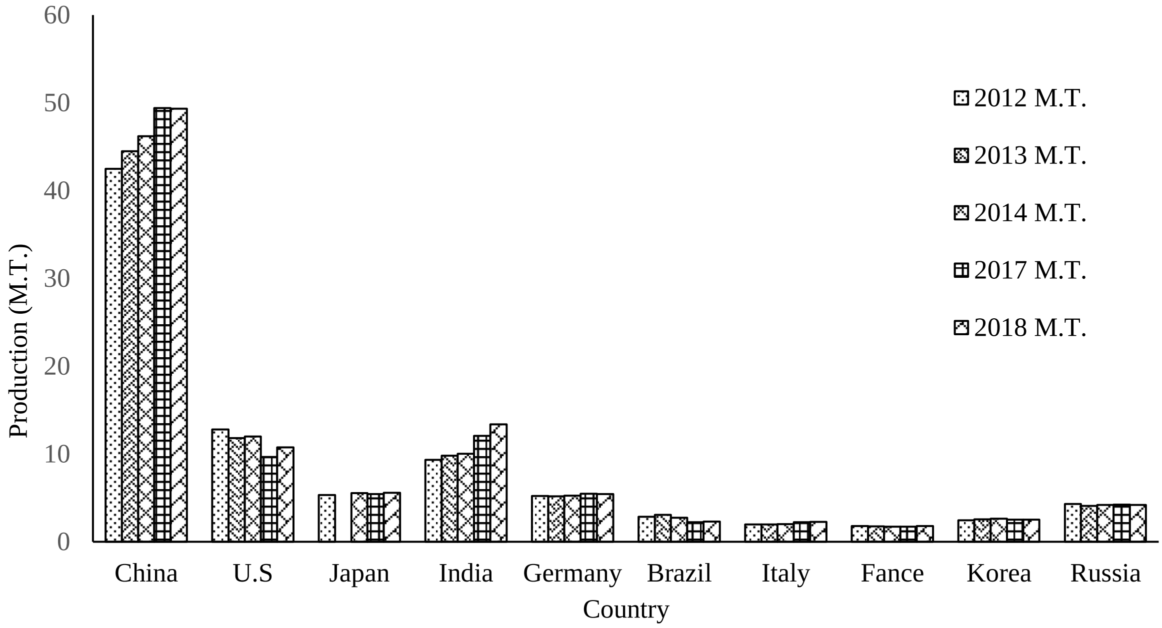

Fig 1.1 Production of casting in the world in million M.T. [42]–[45]

Country	2012		2013		2014		2017		2018	
	M.T.	**R.**	**M.T.**	**R.**	**M.T.**	**R.**	**M.T.**	**R.**	**M.T.**	**R.**
China	42.5	1	44.5	1	46.2	1	49.4	1	49.35	1
U. S	12.8	2	11.8	2	12	2	9.66	3	10.76	3
Japan	5.34	4	-----		5.54	4	5.45	5	5.58	4
India	9.34	3	9.81	3	10.021	3	12.05	2	13.39	2
Germany	5.22	5	5.18	4	5.24	5	5.48	4	5.44	5
Brazil	2.86	7	3.07	6	2.73	7	2.21	9	2.29	8
Italy	1.96	9	1.97	8	2.02	9	2.24	8	2.27	9
France	1.8	10	1.74	9	1.72	10	1.72	10	1.79	10
Korea	2.44	8	2.56	7	2.63	8	2.53	7	2.52	7
Russia	4.3	6	4.1	5	4.2	6	4.22	6	4.2	6
M.T=Million Ton, R= Rank										

Table 1.3 Production of casting in the world in million M.T. [42]–[45]

1.5.2 The Indian Foundry Industry

In India there is an increase of 11% of casting production in 2019 year as compared to previous year[41]. There are 5000 foundry units in India out of which 90% of foundry units that are termed as MSMEs i.e. “Ministry of micro, Small, and Medium” and 1500 units of foundry are termed as “International Quality Accreditation”. The manufacturers of Indian foundries produce from following metal components casts metals for different applications i.e. Pumps/Valves, Wind turbine genrieserators, Cement, Machine tools, Earth Moving, Tractor, Auto, Aerospace, Defense, Power Machinery, Pipe Fittings, etc[41].

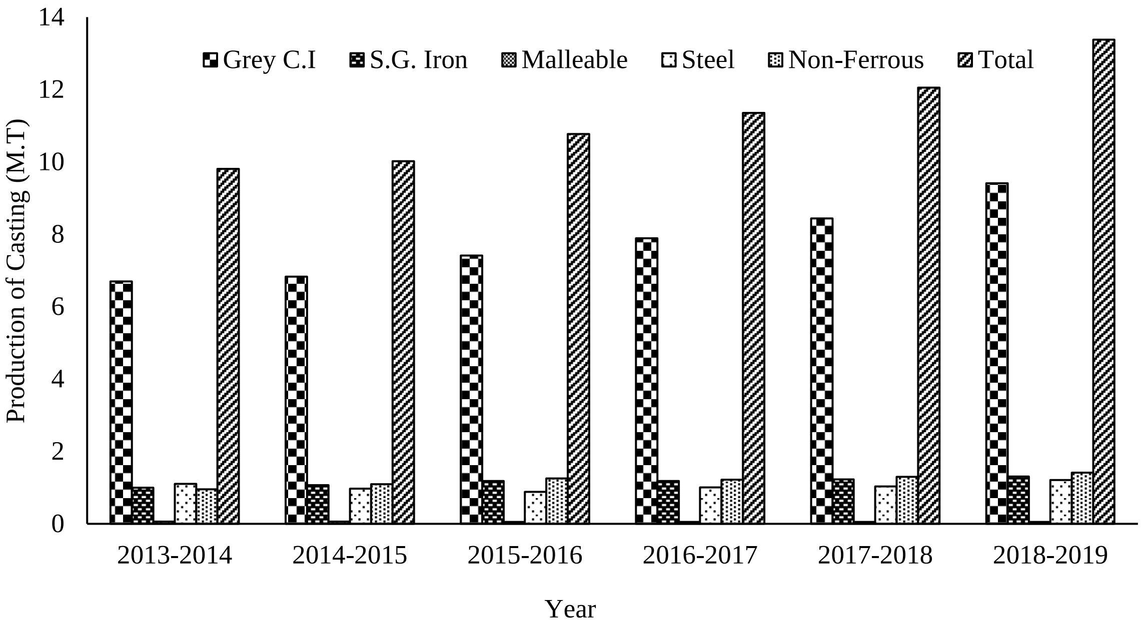

Fig 1.2 Production casting in India in million M.T. (2018-2019)[41]

1.5.3 Major Foundry Clusters (INDIA)

The major foundry clusters for casting metals in India are located in Gurgaon, Faridabad, Ahmedabad, Chennai, Indore, Kolkata, Howrah, Hyderabad, Chennai, Coimbatore, Belgaum, Ahmedabad, Mumbai, Rajkot, Sholapur, Kolhapur, Pune, Agra, Ludhiana, Jalandhar, Batala. Typically, each cluster of foundry casting metals in India is defined as catering to specific end as per use in markets. For example, the Belgaum and the Kolhapur clusters for casting of automobile applications, Howrah cluster for casting application of sanitary, the Rajkot cluster for casting application of diesel engines, the Coimbatore cluster for casting applications for famous for pump-sets etc. [46].

Fig 1.3 Major foundry clusters in India

1.6 Applications of Waste Foundry Sand

As the production in India of WFS is increasing the rate of disposing problems also increases with its prices for disposing and maximum usage of regular sand from natural sources from environment increasing the problems with negatively affecting the environment. Solution for these problems is to recycle waste in a very appropriate manner. Waste foundry sand properties are almost similar to natural sand which draws researcher's attention towards it and many researches are conducted for using it in various construction applications as manufacturing processes i.e. controlled low-strength material (CLSM), asphalts, roofing materials, plastics, glass, paints, grout, concrete, cement, cement manufacturing, rock wool[46], lightweight aggregates, mortar making[39], paving blocks, hydraulic barrier or liner[47],[48], asphalt concrete[49] and brick blocks[24],[26],[40],[49]–[52]. Some of the beneficial application in which WFS can be used is given below.

a) WFS can be suitably used in flowable fills for reinforcement, soil stabilization and construction of roads[53].
b) Waste foundry sand contains a various component like iron and aluminium oxide that can enhances the agricultural soil performance[46].
c) Waste foundry sand can be effectively used in various landfill processes such as highway construction and filling of embankments[47],[54]–[56].
d) Waste foundry sand can be used in pipe bedding and backfill processes[46].

However, using it in concrete is not popular. The main reason behind this is because of following reasons i.e. presence of corrosive metals in WFS, grain size of WFS is unimodal and less as compare to sand. However, it cannot be fully replaced but can be partially replaced with regular sand. Proper and appropriate design mix with waste foundry sand partially replaced with fine aggregates can give good results as compared to conventional concrete.

CHAPTER 2
LITERATURE REIVEW

2.1 General

Increasing quantities of waste materials i.e. (industrial by-product) is a serious issue that have been reports by solid waste management. As the prices of disposing waste are increasing and overuse of natural sand has badly affected the environment, further which causes increase on pollution and extinction of natural sand. The government bodies are finding solution of these problem. There are various types of waste materials produced from industries which have almost similar property as compare to natural sand and due to this it attracts interest of many researchers. For a decade, many researchers are working on the beneficial use of waste materials in various applications of civil engineering.

The early studies have focused on studying for various concrete properties by partially replacing waste foundry sand with fine aggregates. Various studies show that there are good results for inclusion of WFS up to certain amount with fine aggregates in concrete. In this paper, insistence is on the use of waste foundry sand in concrete and various application of concrete. There are several investigations related to the use and various effects of WFS as complete replacement with fine aggregate (natural sand) in concrete.

2.2 Mechanical and Durability Properties of Concrete from Several Literatures

2.2.1 Workability

Guney et al. [26] performed several tests on the production of high strength of concrete by replacing waste foundry sand to a certain point in concrete and studied several effects on the properties of concrete. Author reported that there is decrease in slump and fluidity as the percentage goes on increasing of WFS. The conventional concrete (without WFS inclusion) shows highest slumps as compare to other mixtures i.e. 160 mm. After that there is a systematic decrease in strength and maximum decrement in result were reported at 15% of inclusion of WFS in concrete i.e. 60 mm. Author observed that there is a systematic decrement in strength as the percentage of WFS goes on increasing was due to clay type fine particles present in waste foundry sand which results in decrease in fluidity in concrete[26], [57].

Khatib et al. [57] studied the properties of concrete by fully replacing WFS i.e. (0%-100%) with fine aggregates. Author reported that there was a systematic decrement in slump as the percentage goes on increasing of WFS in concrete. The highest slump was noted at control mix with 0% of inclusion of WFS i.e. 200 mm and After this there was a systematic decrease in slum to 0%for 100% inclusion of WFS in concrete. Author observed that the decrease in slump was due to presence of clay fine particles. That reduces the fluidity in concrete[26],[57].

Bilal et al.[58] examined the properties of concrete by replacing waste foundry sand with fine aggregates in concrete by certain replacement levels up to certain amount of percentages. Author reported that there was almost similar result up to 20% of WFS i.e. 30 mm as compare to control mix i.e. 32% and after that there was a systematic decrement in slump for up to 31.25% for 40% of WFS as compared to controlled mix. The author also reported the values for compaction factor and observed that there were almost similar results up to 20% of inclusion i.e. 0.84 as compare to control mix i.e. 0.85. After that there was a systematic decrease in compaction factor up to 40% of WFS i.e. 0.81. The decrease in workability was observed due to presence of fine particles in waste foundry sand i.e. impurities, ashes and clay type of fine particles etc., presence of these particles reduces the fluidity in concrete by escalating the demand of water[58].

Prabhu et al. [59] performed several test by replacing waste foundry sand by several replacements levels with fine aggregates in concrete and examined the mechanical and durability property of concrete. Author reported that the maximum slump value after immediate mixing of control mix was observed at control mix containing 0% of WFS i.e. 115 mm and after inclusion of WFS there was a systematic decrease in slump for all replacement level but the lowest value for slump was 63 mm for 50% of WFS inclusion in concrete. After 30 minutes immediate mixing of control mix was observed at control mix containing 0% of WFS i.e. 96 mm and after inclusion of WFS there was a systematic decrease in slump for all replacement level but the lowest value for slump was 21 mm for 50% of WFS inclusion in concrete. After 60 minutes immediate mixing of control mix was observed at control mix containing 0% of WFS i.e. 51 mm and after inclusion of WFS there was a systematic decrease in slump for all replacement level but the lowest value for slump was 0 mm for 50% of WFS inclusion in concrete.

There were very few literatures available on workability and it have been observed from these studies that there is systematic decrease in workability with increasing replacement level of waste foundry sand in concrete. Furthermore, the compaction factor value also decrease as the percentage goes on increasing of waste foundry sand in concrete. The main reason behind this decrement of slump and compaction factor values as the percentage goes on increasing in concrete was that WFS contain clay fine particles in it, these particles escalate reduce the fluidity in concrete.

2.2.2 Compressive Strength

Siddique et al.[24] evaluated various mechanical, durability and microstructural property by replacing waste foundry sand with fine aggregates at several percentage levels for different curing ages. Author casted cubes and cylinders for checking various compressive strength values. Author found that concrete containing 30% of WFS have more compressive strength i.e. 38.03 MPa as compare to control mix i.e. 36.27 MPa and other percentages at curing age of 28 days. There was a systematic decrease in compressive strength of cylinder for all values as the percentage of WFS goes on increasing of WFS in concrete as compared to control mix i.e. 26.35 MPa but 30% and 50% of WFS in concrete shows almost similar strength i.e. 24.94 MPa and 24.17 MPa as compare to control mix at 28 days of curing age. Author observed that the compressive strength increases with increase in curing age for all concrete specimens and cubes carries more compressive strength as compare to cylinders.

Aggarwal & Siddique[60] evaluated the possibility of inclusion of waste foundry sand and bottom ash i.e. (industrial by-product) with fine aggregates at various percentage levels i.e. (0%-60%) equally by weight in concrete for different curing ages. Author observed that there was a decrement in compressive strength as compare to control mix at 28 days of curing age i.e. 36.27 MPa. There was a drastic decrease in compressive strength at 60% (WFS+BA) replacement levels i.e. 21.08 MPa as compared to other percentage as all other percentages showed similar results at 28 days of curing age. Author observed that the strength of concrete increase with an increase of curing age.

Guney et al.[26] performed various test by replacing waste foundry sand with fine aggregates at different percentage levels at various curing ages. Author reports that 10% of WFS replacements shoes almost similar results as compared to control mix such as 61.3 MPa at 28 days of curing ages. Author observed that 5% and 15% of WFS inclusion in concrete showed decrement in strength as compared to control mix such as 53.2 MPa and 52.3 MPa and the compressive strength increases with the increase in curing age of the concrete.

Prabhu et al.[28] evaluated the effect of utilization of waste foundry sand in concrete at different percentages level with fine aggregates. Author removed several impurities and particles by using washed waste foundry sand. The waste foundry sand is successfully washed for four times and then it was kept for drying under normal environment conditions for two days. Furthermore, several tests were conducted by using it in concrete and author reported that as compare to control mix there was a systematic decrease in compressive strength for all percentage levels. The 20% WFS percentage level showed almost same strength but marginal decrement of 1.6% as compare to control mix at 28 days of curing age such as 33.14 MPa. Author reported that after 30% of WFs inclusion there was drastic decrease in strength such as for 40% WFS inclusion was up to 11.04% and for 50% WFS inclusion was up to 23.95% as compared to control mix at curing age of 28 days. There was increase of degradation in concrete as the percentage goes on increasing and strength reaches almost half in 100% percentage level of WFS in concrete as compared to original strength[57],[61].

Basar & Aksoy[33] partially replaced the waste foundry sand with sand in concrete and studied the effect of waste foundry sand at different percentage levels. Author reported that there was a systematic decrease in strength at all percentage level as compare to control mix without waste foundry sand. The compressive strength was almost similar at 10% inclusion of WFS in concrete such as 44.1 MPa as compared to control mix such as 43.2 MPa and there was a drastic decrease in strength after 20% of inclusion of waste foundry sand in concrete at 28 days of curing age. The compressive strength increased with the increase in curing age for all the sample of concrete.

Singh & Siddique[34] evaluated the strength properties of waste foundry sand containing concrete. The waste foundry sand is partially replaced with fine aggregate at several percentage levels by weight in concrete and various test are performed. Author reported that there was systematic increase in a strength up to 20% inclusion of WFS and maximum strength was found at 15% of WFS inclusion in concrete i.e. 47.36 MPa compared to control mix at 28 days of curing age i.e. 40.03 MPa. Author observed that the main cause of strength decrement after certain level of increment was because of reduction in surface area of matrix in water-cement gel due to witch fine coarse binding process in concrete does not take place properly[12],[24],[34].

Monosi et al.[62] studied the effect of two type of waste foundry sand coming from same foundry but two different processing stage in the production of concrete and mortars. Author performed several tests by replacing these types of foundry sand in concrete at different percentage level i.e. 0% to 30% and observed that when water cement ratio is low it helps to gain more strength in concrete. There was negligible advantage to gain more strength for waste foundry sand below 0.50 water cement ratio and at low water cement ratio mortar shows negative influences in it. Similar results were reported by Etxeberria et al.[63].

Kaur et al. [64] studied the effect of Fungal treated and untreated waste foundry sand containing concrete at different percentage level. Author reported that the concrete containing treated WFS in concrete shows better results as compared to untreated WFS in concrete. There was systematic decrease in compressive strength after 10% untreated WFS containing concrete and maximum strength was achieved at 10% untreated WFS containing concrete i.e. 33.76 MPa as compare to other percentages at 28 days of curing age. There was systematic increase in all percentages of concrete containing treated WFS as compare to control mix i.e. 33.10 MPa. Author observed that treated WFS in concrete shows more strength as compare to untreated concrete. The main reason behind this is because the treated WFS containing concrete formed new phases of silicate within the mortar material matrix.

Siddique et al. [40] examined on the effective use of waste foundry sand as fine aggregate in concrete at different percentage level for various curing ages. Author reported that the strength increases with the increase in percentage level of waste foundry sand containing concrete. There was 9.8% increment of strength up to 30% inclusion of WFS as compare control mix at 28 days of curing age i.e. 28.5 MPa. The maximum increment in strength was 31.3MPa at 30% inclusion of WFS. The reason behind in increment in strength because maximum amount of silica was found in WFS and WFS has much finer particles as compared to natural sand due to which it forms denser concrete matrix.

Siddique & Sandhu[65] evaluated on the properties of SCC (self-compacting concrete) containing waste foundry sand with natural sand at different percentage levels. Maximum value in strength was observed at 15% of inclusion i.e. 37.42 MPa as compared to other percentages at 28 day of curing ages. There was a 25.94% increment in strength up to 15% inclusion of WFS. Author reports that there was a decrement in strength after 15% inclusion of WFS and there is increment in strength with the increment in curing ages.

Kaur at el.[66] investigated about the properties of fungal treated and untreated waste foundry sand partially replaced with fine aggregate at several percentage levels in concrete. Author reported that concrete containing treated WFS carries more strength as compare to concrete containing untreated WFS. There was a systematic decrease in strength in concrete containing untreated WFS and the maximum strength achieved by untreated WFS was at 10% of inclusion at 28 days of curing age i.e. 33.76 MPa as compare to other percentages. There was a systematic increment in strength in concrete containing untreated WFS and the maximum strength achieved by untreated WFS was at 10% of inclusion at 28 days of curing age i.e. 36.10 MPa as compare to other percentages. The main reason of increment of strength in treated WFS as compare untreated WFS is that treated WFS have Aspergillus spp. (fungal culture) and this helps to form good C-H-S gel in concrete.

Shalokhe & Desai[67] evaluated the properties of concrete by replacing both ferrous and non-ferrous waste foundry sand with fine aggregates in concrete. Author reported that the 30% ferrous foundry sand show maximum increment in the strength i.e. 30.96 MPa and almost have similar result as compared to control mix i.e. 31.7 MPa at 28 days of curing age. Whereas 10% nonferrous foundry sand show maximum increment in the strength i.e. 30.96 MPa and almost have similar result as compared to control mix i.e. 31.7 MPa at 28 days of curing age.

Vardhan et al.[68] performed several test by replacing waste foundry sand with fine aggregates in different grades of concrete (M20, M40, M60). Author reported that 40% of inclusion shows maximum strength in concrete. Author reported that there was a systematic increment in strength up to 40% inclusion of WFS and after that there was a drastic decrease in compressive strength for all grade in concrete. Furthermore, 40% inclusion of waste foundry sand carries a maximum strength for all grades i.e. 34.34 MPa for M20, 54.21 MPa for M30 and 73.21 MPa for M60 at 28 days of curing age.

Bilal et al.[58] evaluated the behavior of waste foundry sand partially replaced with natural sand in concrete at different percentage level and performed several test for compressive strength and (RCS) residue of compressive strength. Author reported that the maximum strength was achieved at 30% inclusion of WFS in concrete. There was an increment up to 7.82% at 28 day of curing age. In RCS, the samples of concrete are check after and before the exposure of required temperature and in RCS author observed that with the rise in the temperature of specimens there was a loss in the compressive strength and 30% yielded inclusion of WFS showed excellent outcomes.

It have been observed from following studies that some of the studies shows 20% inclusion of WFS gives better results as compare to other percentage and some literatures shows 30% inclusion of the WFS in concrete is optimum percentage to use without any negative affect. The fungal treated WFS shows maximum increment in strength as it improves the C-H-S gel formation in concrete as compared to untreated WFS. WFS inclusion with fine aggregates in concrete reduce the density of concrete which reduces the dead weight of concrete structure.

2.2.3 Drying Shrinkage

Khatib & Ellis[50] investigated the properties of concrete containing WFS of various types i.e. blended sand, spent sand and white fine sand) partially and Fully replaced with natural sand at several percentage level. Author reported that as the percentage of WFS increases the drying shrinkage increases in concrete.

Khatib et al.[57] performed several tests by replacing WFS with fine aggregates at 0%-100% replacement levels in concrete and checking the properties of these samples. Author reported that with the increase of WFS percentage level in concrete the shrinkage vale increased in concrete. The maximum increment in value was found at 100% replacement level of WFS i.e. -442.5 micro strain and it was double as compared to control mix i.e. -221.4 micro strain at 28 days of curing age. Author observe that the value of shrinkage was twice at 56 day of curing age.

Less number of researches are available on the drying shrinkage in concrete and by these following literatures this have been observed that Drying shrinkage increases with the increase in WFS percentage level in concrete. It has been reported in studies that 20% replacement level on concrete gives a better result as compared to other percentages and it is the optimum percentage value that can be used in concrete.

2.2.4 Modulus of Elasticity

Siddique et al.[12] studied the influence of waste foundry sand as a partial replacement with fine aggregates in both types of concrete grades (M20 & M30). Author reported that the M20 grade carries better results as compare to M30 grade and inclusion of 15% of WFS have maximum modulus of elasticity as compare to other percentage i.e. 5.9% for M20 grade and 4.8% for M30 grade as compared to control mix at 28 days of curing age.

Guney et al.[26] reported that modulus of elasticity decreases with the increment in percentage level of waste foundry sand. There was a systematic decrease in the value of modulus of elasticity as per WFS percentage level goes on increasing in concrete. There was almost similar result for 10% WFS inclusion in concrete i.e. 38.7 GPa as compared to control mix i.e. 39.1 GPa at 28 days of curing ages.

Prabhu et al.[28] performed several tests and found that there is an increment of modulus of elasticity up to 20% of WFS inclusion in concrete and after 30% there was a systematic decrement in modulus of elasticity. There were almost similar results were found at 10% and 20% inclusion of WFS i.e. 29.7 GPa and 29.1 GPa and after 30% inclusion of WFS there was a systematic decrease in modulus of elasticity in concrete at 28 days of curing age.

Basar & Aksoy[33] examined that there was a systematic decrease in modules of elasticity as the percentage goes on increasing of WFS in concrete. There was almost similar modulus of elasticity for 10% of inclusion i.e. 33.6 GPa as compare to control mix i.e. 34.8 GPa and after 10% inclusion of WFS there was systematic decrease in modulus of elasticity at 28 days of curing age.

Singh & Siddique[34] investigated by performing several test and found that the modulus of elasticity increases with the increase in the percentage level of WFS in concrete. The modulus of elasticity increases up to 15% WFS of inclusion i.e. 6.4% as compare to 29.9 GPa at 28 days of curing age. Author reported that there was a continuous enhancement in modulus of elasticity as the percentage level of WFS goes on increasing.

Siddique et al.[40] found that there was a systematic increase in modulus of elasticity as the WFS percentage goes on increasing in concrete. Author reported that the modulus of elasticity varied between 5.2% to 12% for all replacement levels of WFS in concrete. The maximum increment was found at 30% of replacement level i.e. 28.4 GPa as compared to control mix i.e. 25.1 GPa in concrete.

Naik et al.[69] replaced both clean foundry sand and WFS with fine aggregates in concrete by two proportions (25% and 35%). Author reported that the inclusion of waste foundry sand in concrete showed almost same results i.e. 31.7 GPa for 25% of WFS and 32.6 GPa for 35% of WFS as compared to control mix i.e. 31.7 GPa at 28 days of curing age. The inclusion of clean foundry sand in concrete showed almost same results i.e. 33.4 GPa for 25% of WFS and 33.3 GPa for 35% of WFS as compared to control mix i.e. 31.7 GPa at 28 days of curing age. Author observed that the clean foundry sand carries more strength as compare to waste foundry sand.

It was observed from several literatures that lower grade in concrete showed better modulus of elasticity as compare to higher grade in concrete. Several literatures shows that 20-30% of replacement level of WFS is the optimum percentage that can be used in concrete with any negative effect.

2.2.5 Split Tensile Strength

Siddique et al.[12] reported that M20 grade carries more split tensile strength as compare to M30 grade at all percentage levels of WFS in concrete. The maximum strength in M20 grade was 12.8% achieved upto 15% of inclusion WFS in concrete as compared to control mix i.e. 3.42 MPa and after that there was decrease in strength. The maximum strength in M30 grade was 10.4% achieved upto 15% of inclusion WFS in concrete as compared to control mix i.e. 3.42 MPa and after that there was decrease in strength.

Guney at el.[26] reported that 10% of WFS percentage level carries a maximum increment in strength as compare to other percentage level i.e. 3.27 MPa as compared to all percentage level at 28 days of curing ages.

Prabhu et al.[28] several test performed by replacing prewashed and then dried this WFS in sun at several percentages levels in concrete. The author reported that 40% and 50% inclusion of WFS in concrete showed poor strength as compare to other strength as compared to concrete without WFS at 28 days of curing age i.e. 2.765 MPa. In other percentage levels there was marginal decrement up to 30% inclusion of WFS as compared to control mix.

Siddique et al.[34] performed several test by replacing WFS with fine aggregates in concrete. Author reported the continuous enhancement in strength as the percentage level goes on increasing in concrete. The increment in strength was up to 10.40% from 5%-15% of WFS inclusion in concrete at 28 days of curing as compared to control mix i.e. 4.22 MPa and beyond this the strength decreases in a systematic manner because of presence of fine particles in WFS. Furthermore, Siddique & Sandhu[65] reported almost similar results.

Siddique et al.[40] performed various test by partially replacing WFS with fine aggregates at different percentages. The author reported that there is a increment in strength up to 9% from 10% to 30% inclusion of WFS as compared to control mix at 28 days of curing ages i.e. 2.75 MPa.

Bakis et al.[49] studied the possibility of used of waste foundry sand in asphalt concrete and various test was conducted as per AASTHO T283[70] for indirect tensile strength. Author reported that there was a systematic decrement in indirect tensile strength as the percentage level of WFS goes on increasing in concrete. There was a drastic decrease up to 9.7 kPa for 20% of inclusion of WFS as compared to control mix i.e. 13.9 kPa.

Naik et al.[69] reported that clean/new foundry sand shows more strength as compare to waste/ used foundry sand. The strength found in clean/new foundry sand was 4 MPa at 25% of inclusion and 3.2 MPa at 35% of inclusion in concrete and foe waste/ used foundry sand was 3.6 MPa at 25% of inclusion and 3.1 MPa at 35% of inclusion in concrete at 28 days of curing age. Furthermore, Basar et al.[33] and Saraswati et al.[71] reported almost similar results that there was a systematic decrement in strength as the percentage of inclusion for WFS goes on increasing in concrete.

Salokhe et al.[67] reported that there was a increase on strength of ferrous foundry sand as compared to non-ferrous foundry sand. Author found that both foundry sands carries maximum increment in strength at 20% of inclusion of WFS but ferrous foundry sand carries more strength as compared to non-ferrous foundry sand. The strength found is 2.64 MPa for non-ferrous WFS and 2.85 MPa for ferrous WFS at 28 days of curing age and these strengths are less as compared to control mix in concrete i.e. (3.3 MPa).

Vardhan et al.[68] concluded that 40% inclusion of WFS in concrete give the maximum results in strength as compare to other percentages for all grades in concrete. Author reported that the strength found for M20 grade was 4.02 MPa, for M40 grade was 6.13 MPa, for M60 was 8.89 MPa and then there was a systematic decrease in split tensile strength.

Bilal et al.[58] examined that the 30% inclusion of WFS in concrete gives the maximum strength as compare to other percentages. The strength found increased up to 9.87% as compared to control mix i.e. 3.28 MPa at 28 days curing ages.

It has been observed from various studies that 15%-20% of WFS inclusion in concrete gives the better results in concrete as compare to other percentages but several studies shows that 30%– 50% shows optimum value.

2.2.6 Flexural Strength

Siddique et al.[60] examined on the various effect of waste foundry sand and bottom ash containing concrete which was equally replaced in fixed amount with fine aggregates at different percentage levels i.e. (0%-60%). Author found maximum strength at 30% of inclusion of both bottom ash and waste foundry sand in equal quantities i.e. 4.34 MPa but it was less as compared to control mix at 28 days of curing age i.e.4.44 MPa.

Prabhu et al.[28] performed several tests and concluded that there was a systematic decrease in flexural strength. The 10% inclusion of WFS and 20% inclusion of WFS caries almost same strength i.e. 3.986 MPa and 3.988 MPa as compare to control mix at 28 days of curing age i.e. 4.089 MPa but these values of mixes shows less strength as compare to control mix.

Vardhan et al.[68] concluded that 40% inclusion of WFS in concrete give the maximum results in strength as compare to other percentages for all grades in concrete. Author reported that the strength found for M20 grade was 5.96 MPa, for M40 grade was 8.73 MPa, for M60 was 10.53 MPa and then there was a systematic decrease in split tensile strength.

Bilal et al.[58] examined that the 30% inclusion of WFS in concrete gives the maximum strength as compare to other percentages. The strength found increased up to 10.35% as compared to control mix i.e. 6.15 MPa at 28 days curing ages.

Less number of researches are available on the effect of waste foundry sand containing concrete on the properties of flexural strength. It has been observed from different studies that 30% of percentage level is an optimum value for using WFS in concrete without any negative influence.

2.2.7 Abrasion Resistance

Naik et al.[27] examined the effect of waste foundry sand and fly ash containing concrete at different percentage levels. Author reported that all percentage levels of non-air train carried more values of abrasion as compared to air trains values in concrete. The maximum depth was found at 45% UFS + 34% FA percentage level for non-air trains in concrete at 60 minutes i.e. 1.9 mm as compared to other percentage level this is more as other percentage level shows less than 1.4 mm abrasion depth in concrete. The maximum depth was found at 43% UFS + 40% FA percentage level for air trains in concrete at 60 minutes i.e. 2.4 mm at 28 days of curing age.

Singh & Siddique[34] performed various test and concluded that 5% of inclusion of

WFS in concrete showed higher abrasion resistance value as compared to other percentages for 60 minute of abrasion time at 28 days of curing age and all percentage levels almost shows similar results. The maximum abrasion was found at 5% i.e. 2.6 mm which is higher as compared to other percentage levels but lesser then control mix at 28 days of curing age i.e. 2.84 mm for 60 minutes abrasion time. Author reported that 15% WFS inclusion is suitable i.e. 2.28 mm for making structures and applications of concrete.

Less number of studies are available on abrasion resistance and it was observed that 20% WFS inclusion in concrete can be optimum value that can be used to make concrete without any negative effects.

2.2.8 Ultrasonic Pulsed Velocity

Siddique et al.[12] examined that the M20 grade carries more UPV value as compared to M30 grade in concrete. There was a increment of UPV value in M20 grade was up to 0.99% from 5% to 15% of WFS as compared to control mix i.e. 4010 m/s and there was increment of UPV value in M30 grade was up to 0.83% from 5% to 15% of WFS as compared to control mix 4231 m/s at 28 days of curing age. Author observed that the value of UPV varied between 4010 m/s to 4300 m/s of M20 and M30 grade in concrete at 28 days of curing age. As per BIS 13311 (Part 1)[72], the value which is ranging between (3500 m/s and 4500 m/s) comes under the quality of good zone in concrete mixes.

Khatib et al.[57] examined that there is systematic decrease in UPV value as percentage goes on increasing of WFS content. Author performed several tests by partially and fully replacing WFS in concrete and reported that there was almost similar strength in concrete i.e. 3792 m/s and 3721 m/s for 20% WFS and 40% WFS as the percentage go on increasing up to 100% of WFS the strength goes on decreasing as compared at 28 days of curing age to i.e. 3794 m/s. Author observed that there was a increase in strength with the increase in curing age of concrete.

Khatib et al.[61] performed several tests by replacing waste foundry sand by partially and fully replacing in concrete. Author reported that the values of UPV varied from 3500 m/s to 4800 m/s at all the curing ages in concrete. Author reported that with the increase in curing age of concrete there is an increment in the density of concrete and with the increase in WFS there is a decrease in UPV value.

Bilal et al.[58] examined that 30% of inclusion of WFS in concrete showed higher strength as compared to other percentages and also by control mix. Author reported for heat/fire exposed and unexposed concrete samples that the UPV values decreases as the temperature rises above 500°C and there is a drastic decrease in value as the temperature rises from 600°C.

the main reason behind this is as the temperature rises it increase the level of range for wide cracks in concrete that causes the low velocity values in concrete.

2.2.9 Water Absorption

Basar& Aksoy[33] investigated about the behavior of water absorption values in concrete and reported that with the increase in WFS in concrete the water absorption value also increase. The highest value of water absorption was found at 40% inclusion of WFS i.e. 6.6% as compared to all other percentage and lowest percentage value was at 0% inclusion of WFS i.e. 5%. The main reason of increment was presence of fine particles in WFS so as the WFS increases in concrete the water absorption values also increases.

Kaur et al.[64] reported that the fungal treated WFS shows better results as compared to untreated WFS in concrete. The 20% untreated WFS in concrete showed more better results i.e. 0.5% as compare to treated WFS in concrete i.e. 0.9% after 28 days of curing age. Author observed decreased of 50% of porosity and up to 44% of water absorption for concrete made with 20% WFS fungal treated after 28 days of curing age in concrete. Similar results were observed in the research of Kaur et al.[66].

Khatib et al.[57] investigated that as the percentage level and time of immersion for concrete containing WFS goes on increasing the water absorption values also goes on increasing after 28 days of curing age. Similar results were observed in the research of Khatib et al.[61].

Salokhe et al.[67] investigated that ferrous foundry sand shows better results as compared to non-ferrous foundry sand in concrete. The better results showed of water absorption by ferrous foundry sand at 20% of inclusion i.e. 1.13% and for non-ferrous foundry sand was at 10% of inclusion i.e. 1.54% at 28 days of curing age. The maximum increment showed by ferrous foundry sand at 30% of inclusion i.e. 1.93% and for non-ferrous foundry sand was at 30% of inclusion i.e. 1.91% at 28 days of curing age.

2.2.10 Water Permeability

Siddique et al.[73] reported that as the curing ages of concrete increases the reduction in flow decreases in concrete. The maximum reduction in flows was on 28 days of curing age i.e. 19.1% this value is huge as compared to 56 days of curing age in concrete i.e. 1.8% for the concrete containing 20% of WFS with 5 to 15% of metakaolin.

Khatib et al.[61] reported that there is an increment in capillary action as the percentage level of WFS increases in concrete. Author observed that at 60%-100% of WFS in concrete depicted entrance i.e. (up to 3 times as compared to 0%) as compared to 0%-30% of percentage level for WFS in concrete.

Prabhu et al.[59] investigated that there was an increase in permeability coefficient values as the percentage level of WFS increase in concrete. Author reported that 30% of WFS does not shows any negative influence in concrete at 180 day of curing age i.e. 7.2×10^{-12}m/s and it is below as compared to ACI 301 recommendation i.e. 15×10^{-12} m/s[59], [74]. As per ACI 301 recommendation, this is the suitable percentage that we can use in concrete.

2.2.11 Carbonation Depth

Siddique et al.[24] reported that the carbonation depth increases on the concrete and in several percentages of WFS containing concrete with the increase in curing ages. Author observed that the increment in carbonation depth is 0.17 mm for with increment for each 10% of WFS percentage level at 90 days of curing age and after 365 days it increases up to 0.33 mm of carbonation depth. And as per table no. 2.1 , the typical value for good concrete as C (coefficient) never exceed 6 $mm/yr^{0.5}$ [24],[75]. The increment in carbonation depth leads to poor workability in concrete.

Table 2.1 Typical values of C for quality of concrete[24],[75]

C ($mm/yr^{0.5}$)	**Concrete**
>9	Poor
9 > C >6	Average
<6	Good

Prabhu et al.[59] investigated that the carbonation depth increase with the increase in curing age in concrete and with all percentage level in concrete. The author reported that 30% inclusion of waste foundry sand in concrete showed the value which comes under the good concrete at 180 days and 360 days of curing age i.e. 2.01 mm and 3.18 mm.

2.2.12 Sulphate Resistance

Siddique & Sandhu[65] investigated on the concrete containing WFS first cured for 28 days and then immersed in 50g/l $MgSo_4$ for several days of curing. Author reported that 10% inclusion of WFS in concrete showed more strength as compare to all percentages in concrete for all curing ages. If concrete samples immersed for a long time it affects the strength properties of concrete.

Prabhu et al.[59] reported that as the curing age of concrete increased containing WFS and immersed in $MgSO_4$ and $NaSO_4$ solution there is a decrease in strength. Author observed that there was a reduction in compressive strength at 180 days up to 6.18% and at 360 days up to 13.14%. The increment in strength was because of the waste foundry sand that increases the strength of magnesium sulphate due to presence of traces of Sulphur (SO_3) in it which causes deterioration in concrete and enhances the ettringite formation[59],[76]–[78].

2.2.13 Chloride Ion Penetration

Siddique et al.[12] investigated that with increase in WFS in concrete there is a decrease in coulomb charge for both types of grades in concrete i.e. M20 grade and M30 grade. Author reported that there is a reduce in the coulombs value for both the grades of concrete i.e. M20 grade and M30 grade at 15% inclusion of WFS i.e. 1110 coulombs and 940 coulombs as compared to control mix i.e. 1399 coulombs and 1240 coulombs at the curing age of 91 days. Author observed that M20 grade carries more coulomb charge which indicates that concrete have densification in its microstructure. Waste foundry sand contain filler material as fine particle that makes inner part stronger of concrete matrix structure.

Siddique et al.[24] reported that the rapid chloride permeability test values was less for 20% and 30% inclusion of WFS in concrete i.e. 273.3 and 273.6 coulombs as compared to control mix i.e. 322 coulombs at 90 days of curing age. Author found maximum value at 60% of inclusion of WFS in concrete i.e. 477 coulombs at 90 days of curing age.

Siddique al.[60] examined that as the percentage goes on increasing the coulombs values also goes on increasing and as the curing age increases there is decrease in coulomb charge in concrete. Author found maximum value at 60% inclusion of WFS + BA (waste foundry sand and bottom ash) i.e. 741 coulombs and minimum value was found at control mix i.e. 578 coulombs at 90 days of curing age. For 365 days of curing age, maximum value was found at 20% inclusion of WFS + BA (waste foundry sand and bottom ash) i.e. 306 coulombs and minimum value was found at control mix i.e. 578 coulombs at 90 days of curing age. Author reported that the chloride permeability is affected by testing age, cement type, w/c ratio and condition of curing age in concrete. As per ASTM C1202[79], the coulombs value which comes between the range of 1000 to 2000 is known for low permeability and below 1000 is known for very low permeability i.e. given in table no. 2.2. The various value for chloride ion ingress with the level of permeability is shown in table no.

Table 2.2 Chloride-Ion Penetrability Based on Charge Passed as per ASTM C1202[79]

Charge Passed (coulombs)	Chloride Permeability
>4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very Low
<100	Negligible

Prabhu et al.[59] reported that 30% of inclusion of WFS does not shows any negative effect in concrete and as per ASTM C1202[79], the value for penetration is very low for 180 days of curing age i.e. 621 coulombs and foe 365 days of curing age i.e. 728 coulombs. Author observed that as the curing age increases the coulomb charge value also increases in concrete.

2.2.14 Micro Structural Analysis

Siddique et al.[60] examined the C-S-H gel (Calcium-Silica-Hydrate) formation which is primarily influenced by size of grains, composition of dispersed phase or stage, types of particles and pore structures. Author examined the SEM micrograph of concrete containing bottom ash (BA) and waste foundry sand (WFS) partially replaced by regular sand in concrete up to 60% percentage level on the required magnification of 1500×. The 10% inclusion in concrete showed decrease in voids and C-H-S gel in concrete was not spread extensively as compared to control mix (0% inclusion of WFS+BA). The 50% inclusion showed needle like structure in micrograph for concrete and the 60% inclusion showed lower strength due to less C-S-H gel formation in concrete. The structure of concrete containing WFS and BA showed disintegrated in concrete.

Siddique et al.[81] reported that concrete containing fungal treated WFS showed less pores in concrete surface as compared to untreated concrete and for control mix. The binding ability of fungal causes reduction in porosity, filling of pores in concrete and this helps for increasing in strength of concrete. Similar type of results were reported by Siddique et al.[64].

2.3 Summary of Literature Review

The following chapter summarize the effect of waste foundry sand on mechanical and durability properties of concrete by replacing it fully and partially with fine aggregates in concrete. Various literatures show that waste a foundry sand can be used up to certain amount and after that it causes negative effects on the properties of concrete. The main cause of this is the particle size of waste foundry sand is less as compared to natural sand. Furthermore, it contains many impurities like saw dust and clay which creates air voids in concrete and reduces the density as well as specific gravity of concrete. The presence of fine particles in WFS reduces the surface area leads to affect the water-cement gel matrix due to which binding process do not occurs properly in concrete. Thus, the increasing content of WFS after certain amount in concrete leads to affect the mechanical and durability properties of concrete. Upto certain amount it has been examined that there is increment in strength and shown better results in mechanical and durability properties of concrete. The better results obtain upto certain amount was due to the presence of fine particles in WFS that acts as good packing material, and this ultimately results in the formation of denser concrete mix. Furthermore, The WFS contains silica content in high amount which helps in the formation of C-H-S gel and this is due to the packing behavior of matrix particle. From various literatures it has been observed that upto 20%-30% of waste foundry sand as a replacement level can be used for making concrete and its structures.

2.4 Research Objectives

The main objective of the investigation is to study the effective use of waste foundry sand in concrete by partially replacing with natural sand in concrete without any negatively affecting the properties of concrete. In this study the waste foundry sand is partially replaced with natural sand at several percentage levels. The different of this investigation are given below:

a) To examine the effect of waste foundry sand in M40 i.e. (high grade of concrete).
b) To attain the required specific strength in control mix.
c) To compare the mechanical properties i.e. (compressive strength, splitting tensile strength and flexural strength) of concrete containing waste foundry sand by partially replacing regular sand with conventional mix.
d) To compare the durability properties i.e. (sulphate resistance) of concrete containing waste foundry sand by partially replacing regular sand with conventional mix.
e) To find the optimum percentage of waste foundry sand, so it can be used without any negatively affecting the properties of concrete and can be used suitably for making concrete paver blocks.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 General

The chapter describe the details of various materials used in experiment and methodology that has been followed in this program for evaluation of different properties like mechanical property i.e. (compressive strength, splitting tensile strength and flexural strength), durability properties i.e. (sulphate ion resistance) by replacing the waste foundry sand with fine aggregates at several percentage levels for fixed interval of curing ages. This chapter also describes about the procedure that have been adopted for physical testing of various materials such as cement, sand, coarse aggregates and waste foundry sand and this chapter includes the details of specimens used in testing, procedure of preparation of specimens and casting for different test, details of mix design, age of specimens for testing and various testing procedures used in tests. The flow chart describes the overview of experimental program.

3.2 Materials and Methods

The effect of using waste foundry sand containing concrete was investigated at various percentages as partial replacement with fine aggregates. Also, effect on durability and mechanical properties in concrete containing waste foundry sand.

3.2.1 Cement

Portland pozzolana cement (PCC) was used which was conformed as per IS 1489-Part-1[82], the various physical properties of cement are initial and final setting time, specific gravity, standard consistency, and fineness which are evaluated by the following procedure given in IS 1489-Part-1[82].

Fig 3.1 Portland pozzolana cement (PCC)

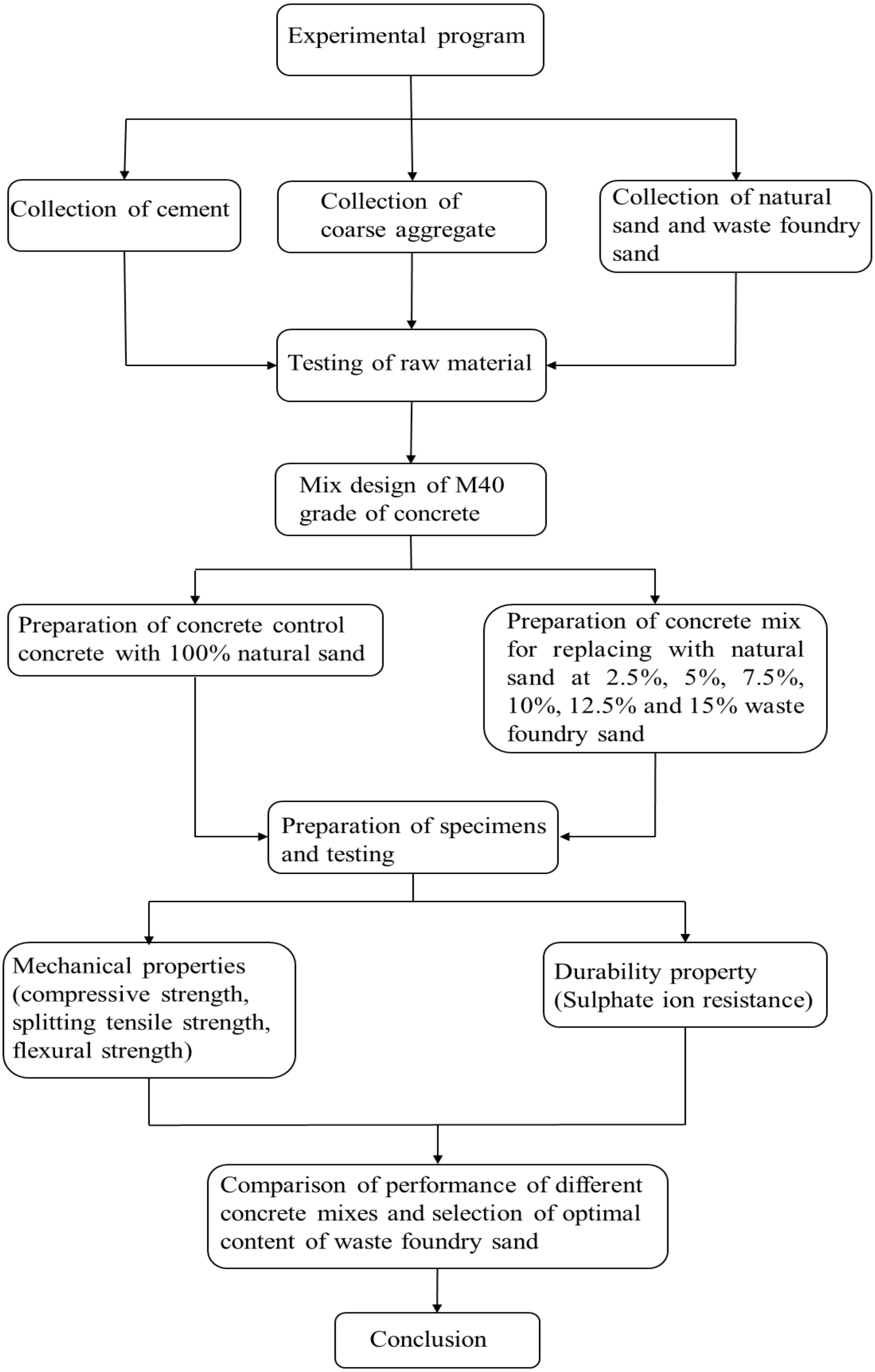

Fig 3.2 Flow chart of Experimental program

3.2.2 Natural Sand

The material was locally available with 4.75 mm is the nominal maximum size of the fine aggregates. The fine aggregates were tested as per BIS: 383–1970[83]. Specific gravity, fineness modulus, water absorption and sieve analysis was determined by BIS: 383–1970[83].

Fig 3.3 Natural sand

3.2.3 Coarse Aggregates

The material was locally available with 4.75 mm is the nominal maximum size of the fine aggregates. The fine aggregates were tested as per BIS: 383–1970[83]. Specific gravity and water absorption was determined by BIS: 383–1970[83].

Fig 3.4 Coarse aggregates

3.2.4 Waste Foundry Sand

The Waste foundry sand was collected in bags from caste iron foundry in Batala, Jalandhar (Punjab). Waste foundry sand was tested according to BIS: 383–1970[83]. Specific gravity, fineness modulus, water absorption and sieve analysis was determined by BIS: 383–1970[83].

Fig 3.5 Waste foundry sand

3.2.5 Super Plasticizer

Super plasticizer is also defined as water reducer and these are used in making or production for high grade concrete. Super plasticizers reduce 30% of water content in concrete and it decelerate the curing time of concrete. They effectively improve the performance of fresh past of concrete.

Fig 3.6 Super plasticizer

3.2.6 Magnesium Sulphate

The magnesium sulphate powder was collected from nearby chemist shop. It is the admixture which is based on polycarboxylic ether.

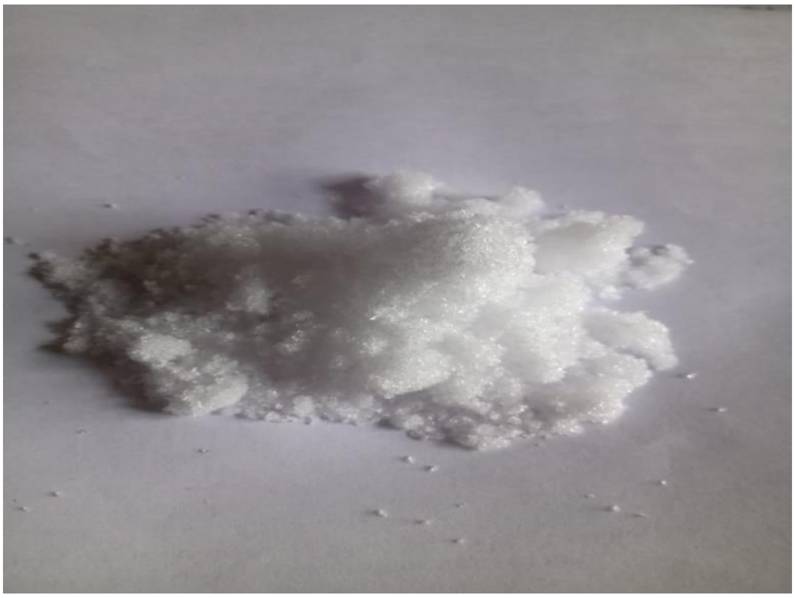

Fig 3.7 Magnesium sulphate

3.2.7 Water

Water is very important material that helps in achieving the required strength in concrete. In the essential process of hydration, it requires almost $3/10^{th}$ of its water weight. If water is not properly used in concrete as per required in design, it can negatively affect the structure made by concrete. If water is used in less amount it can affects the workability which can further affects the mechanical and durability properties in concrete and if it is used in more amount it can cause bleeding and segregation in the structure of concrete. Water ranging between 6-9 is fit for drinking and can be used in concrete.

3.3 Mix Proportion

Control mixture (M-1) of concrete was designed according to Standard Specifications BIS: 10262–1982[84] and BIS 456-2000 to have 40 MPa compressive strength of 28 days of curing ages. Additional concrete mixtures (M-2, M-3, M-4, M-5, M-6 and M-7) were designed by replacing waste foundry sand at several percentages (2.5%, 5%, 7.5%, 10%, 12.5% and 15%) by weight with fine aggregates. The water cement ratio is kept constant for all designed concrete mixtures. The mix proportion for all concrete mixtures are given in table no.3.1.

Fig 3.8 Addition of waste foundry sand in concrete mix

Table 3.1 Mix design of concrete mix for M40 grade containing waste foundry sand

Mix no.	**M-1**	**M-2**	**M-3**	**M-4**	**M-5**	**M-6**	**M-7**
Cement (kg/m^3)	398.57	398.57	398.57	398.57	398.57	398.57	398.57
Waste foundry sand (%)	0	2.5	5	7.5	10	12.5	15
Waste foundry sand (kg/m^3)	0	21.16	42.34	63.51	84.68	105.85	127.02
Sand (kg/m^3)	850	828.75	807.5	786.25	765	743.75	722.5
W/C	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Water (kg/m^3)	139.5	139.5	139.5	139.5	139.5	139.5	139.5
Coarse aggregates (kg/m^3)	1081.836	1081.836	1081.836	1081.836	1081.836	1081.836	1081.836

3.4 Specimens Preparation and Casting

A very careful procedure was adopted in the mixing, batching and casting operations. The cement, fine aggregates, coarse aggregates, waste foundry sand, super plasticizer and water were weighed. Fine aggregates were replaced with waste foundry sand in fixed amount and dry mixed separately to uniform color. The cement, fine aggregates, coarse aggregates, waste foundry sand were dry mixed separately to uniform color. Superplasticizer was added in water separately in different container as per requirement with required quantity. These were hand mixed or mixed in machine to a uniform color on a watertight platform. All sample of concrete mixture were prepared with accordance of Indian Standard Specifications BIS: 516–1959[85].

Fig 3.9 Dry mix of concrete mix

Fig 3.10 Mixing of concrete mix with mixer

The samples were allowed to kept first at ambient condition of temperature 24 hours in the steel mold. After 24 hours, these samples with care were demoulded so that edges of sample could not break, and testing can be done in good manner. Then samples were placed in curing tank at ambient temperature of 27± 2 °C and cured till testing or as per requirement of the test. All specific details of various tests are given in table no.3.2.

Table 3.2 Detail of specimens

Test	**Specimen**	**All testing ages**
Compressive strength	150 mm cubes	7, 28 and 56 days
Splitting tensile strength	150 mm x 300 mm	7, 28 and 56 days
Flexural strength	100 mm x 100 mm x 500 mm	7, 28 and 56 days
Sulphate ion resistance	150 mm cubes	14 nd 28 days

3.5 Testing Procedure

After curing ages of required time period, the samples were taken out from curing tank and then the surface of each samples are wiped off. All samples tests for compressive strength and flexural strength were performed as per Indian Standard Specifications BIS: 516–1959[85] in which cubes and beams size was kept 150x150x150mm and 100x100x500mm. All samples tests for split tensile strength were performed as per Indian Standard Specifications BIS: 5816–1999[86] in which cylinders size were kept 150x300mm and Sulphate resistance test for samples were performed as per ASTM C452-06 in which cubes size were kept 150x150x150 mm. The compressive, splitting and flexural testing of samples was done after 7, 28 and 56 days of curing age and sulphate ion resistance testing for samples was done after 14 and 28 days of curing age.

In this work the sulphate resistance test was conducted by immersing samples in 7% of magnesium sulphate for 14 and 28 days of curing age. The samples before immersion in magnesium sulphate was kept 28 days of curing age at normal temperature in water and then compressive strength is conducted on these samples. The following test procedure of all properties is given below:

Fig 3.11 Casting of samples

3.5.1 Compressive Strength

Compressive strength is the important mechanical property that used to give characteristic compressive strength of concrete. Compressive strength for all concrete samples were done as per Indian Standard Specifications BIS: 516–1959[85]. Furthermore, the cube sizes in this was kept as 150mm×150mm×150mm and the test was evaluated at the curing age of 7 days, 28 days and 56 days. Concrete samples were kept demoulded for 24 hours and after casting, the concrete samples were placed in curing tanks for required curing age. Then after each curing age the samples were taken out and then the testing was done in CTM by applying specified load rate i.e. 140 kg/cm^2/min. Then the load of the machine was increased until the concrete specimens do not break, and the maximum amount of load was taken and noted down of concrete specimens.

Fig 3.12 Compression Testing Machine

The formula used to calculate compressive strength is:

$$\sigma = P/A$$

where,

A = Area of cross section of cube (mm2)

P = Maximum load sustained by the cube (N)

σ = Compressive strength (N/mm^2)

The various results of compressive strength testing were done for 3 specimens at 7 days, 28 days and 56 days of curing age for each concrete sample in N/mm^2.

Fig 3.13 Casting of Cube

Fig 3.14 Sample of cube

3.5.2 Splitting Tensile Strength

The concrete is brittle in nature so it is very weak in tension due to which it cannot resist direct tension. This is the indirect method for determining the tensile strength. Splitting tensile strength for all concrete samples were done as per Indian Standard Specifications BIS: 5816–1999[86]. Furthermore, the cylinder sizes in this was kept as 150mm diameter and 300mm height and the test was evaluated at the curing age of 7 days, 28 days and 56 days. Concrete samples were kept demoulded for 24 hours and after casting, the concrete samples were placed in curing tanks for required curing age. Then after each curing age the samples were taken out and then the testing was done in UTM by applying specified load rate i.e. 1.2 $N/mm^2/min$ to 2.4 $N/mm^2/min$. Then the load of the machine was increased until the concrete specimens get crack along with the vertical plan, and the maximum amount of load was taken and noted down of concrete specimens.

Fig 3.15 Demoulding the cylinder

The formula used to calculate compressive strength is:

$$\sigma st = P/\pi DL$$

where,

P = Maximum load sustained by the cylinder (N)

D = Diameter of cylinder (mm)

L = Length of cylinder (mm)

σst = Splitting Tensile Strength (N/mm^2)

The various results of splitting tensile strength testing were done for 3 specimens at 7 days, 28 days and 56 days of curing age for each concrete sample in N/mm^2.

Fig 3.16 Samples of cylinder

3.5.3 Flexural Strength

Flexural strength is a basic mechanical property is co related with compressive strength and splitting tensile strength. Flexural strength for all concrete samples were done as per Indian Standard Specifications BIS: 516–1959[85]. Furthermore, the beam sizes in this was kept as 100mmx100mmx500mm and the test was evaluated at the curing age of 7 days, 28 days and 56 days. Concrete samples were kept demoulded for 24 hours and after casting, the concrete samples were placed in curing tanks for required curing age. Then after each curing age the samples were taken out and then the testing was done by applying specified load rate i.e. 180 kg/min. Then the load of the machine was increased until the concrete specimens do not break, and the maximum amount of load was taken and noted down of concrete specimens.

Fig 3.17 Casting of beam

The formula used to calculate Flexural strength is:

a) The formula used when ‘a’ in 100 mm is greater than 13.3 cm.

$$f_b = PL/bd^2$$

b) The formula used when ‘a’ in 100 mm is greater than 11 cm.

$$f_b = 3PL/bd^2$$

where

b = width of the specimen (measured in cm)

d = depth of the specimen at the point of failure (measured in cm)

L= length of the span on which the specimen was supported (measured in cm)

P = maximum load applied to the specimen (measured in kg)

f_b= modulus of rupture (N/mm^2)

a = the distance between the line of nearer support and fracture, measured on the tensile side of the center line for the specimen

c) If the a is less than 11.0 cm the results shall be discarded from the test performed.

The various results of flexural strength testing were done for 3 specimens at 7 days, 28 days and 56 days of curing age for each concrete sample in N/mm^2.

Fig 3.18 Samples of beams

3.5.4 Sulphate Resistance

Sulphate resistance for all concrete samples were done as per Indian Standard Specifications. In this work the sulphate resistance test was conducted by immersing samples in 7% of magnesium sulphate for 14 and 28 days of curing age. The samples before immersion in magnesium sulphate was kept 28 days of curing age at normal temperature in water and then compressive strength is conducted on these samples. Furthermore, the cube sizes in this was kept as 500x500x500mm. Concrete samples were kept demoulded for 24 hours and after casting, the concrete samples were placed in curing tanks for required curing age. Then after each curing age the samples were taken out and then the testing was done by applying specified load rate i.e. 180 kg/min. Then the load of the machine was increased until the concrete specimens do not break, and the maximum amount of load was taken and noted down of concrete.

The formula used to calculate compressive strength is:

$$\sigma = P/A$$

where,

A = Area of cross section of cube (mm2)

P = Maximum load sustained by the cube (N)

σ = Compressive strength (N/mm^2)

The various results of sulphate resistance testing were done for 3 specimens at 14 days and 28 days of curing age for each concrete sample in N/mm^2.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

In this chapter, various results are discussed that are reported in experimental programs. In first section, the physical testing results are given i.e. cement, natural sand, waste foundry sand and coarse aggregates. For cement, the following physical test that are done is initial and final setting time, specific gravity, normal consistency and fineness. For natural sand, the following physical test that are done is specific gravity, sieve analysis, water absorption. For waste foundry sand, the following physical test that are done is specific gravity, sieve analysis, water absorption. For coarse aggregates following physical test are done i.e. water absorption and specific gravity. In next section, the waste foundry sand is partially replaced with fine aggregates at various percentage levels i.e. 2.5%, 5%, 7.5%, 10%, 12% and 15% and by replacing waste foundry sand with natural sand various tests were conducted on mechanical and durability properties of M 40 grade concrete. Mechanical property includes compressive strength, splitting tensile strength and flexural strength, and durability property include sulphate resistance. The mechanical and durability properties are also discussed with other studies as well as their change in strength by inclusion of waste foundry sand in concrete.

4.2 Properties of raw materials

4.2.1 Cement

Pozzolana Portland cement PPC was used in making for all samples of concrete mix. The PPC was uniform in colour and was free any type of hard lumps. Table no.4.1 gives the physical properties of cement.

Table 4.1 Physical properties of cement

Physical test	**Results obtained**	**BIS: 1489(part 1):1991 Specification**
Fineness (retained on 90-µm sieve)	3%	<10%
Standard consistency	33%	------
Initial setting time (min)	92 minutes	30 minutes (min)
Final setting time (min)	584 minutes	600 minutes (max)
Specific gravity	2.89	------

4.2.2 Naturel Sand

The material was locally available with 4.75 mm, that is the maximum nominal size of the fine aggregates. The all test of natural sand was done according to the Indian Standard Specifications which is given in BIS 383:1970[83] and by doing these test this sand categorized under zone 2. The physical properties of natural sand are given in table no. 4.2.

Table 4.2 Physical properties of natural sand

Property	**Fine aggregate**
Maximum size (mm)	4.75 mm
Specific gravity	2.63
Total water absorption (%)	1.92%
Fineness modulus	2.78

4.2.3 Waste Foundry Sand

The Waste foundry sand was collected in bags from caste iron foundry in Batala, Jalandhar (Punjab). The waste foundry sand was tested according to BIS: 383–1970[83] and physical properties of waste foundry sand is given in table no. 4.3.

Table 4.3 Physical properties of waste foundry sand

Property	**Waste foundry sand**
Maximum size (mm)	4.75
Specific gravity	2.66
Total water absorption (%)	1.26%
Fineness modulus	1.03

4.2.4 Coarse Aggregates

The material was locally available with 12.5 mm, that is the maximum nominal size of the coarse aggregates. The coarse aggregates were tested according to BIS: 383–1970[83]. The physical properties of coarse aggregates are given in table no. 4.4.

Table 4.4 Physical properties of coarse aggregates

Property	Coarse aggregates
Maximum size (mm)	12.5 mm
Specific gravity	2.67
Total water absorption (%)	2.16%
Moisture content	nil

4.2.5 Sieve Analysis of Aggregates

Sieve analysis of Aggregates i.e. natural sand and waste foundry sand was done as per to BIS: 383–1970[83]. The materials like natural sand and waste foundry sand were collected locally in large amount. On the basis of sieve analysis was done as per BIS: 383–1970[83], the natural sand is categorized as zone 2 and waste foundry sand as zone 4. The sieve analysis of these aggregates are given below:

Table 4.5 Sieve analysis of natural sand

Sieve Size	Weight retained (gm)	% retained	Cumulative % retained	% passing
10mm	0	0	0	100
4.75mm	12	1.2	1.2	98.8
2.36mm	2	.2	1.4	98.6
1.18mm	383	38.8	39.7	60.3
600 microns	171	17.1	56.8	43.2
300 microns	271	27.1	83.9	16.1
150 microns	116	11.6	95.5	4.5

Table 4.6 Sieve analysis of waste foundry sand

Sieve Size	Weight retained (gm)	% retained	Cumulative % retained	% passing
10mm	0	0	0	100
4.75mm	0	0	0	100
2.36mm	0	0	0	100
1.18mm	3.1	.31	.31	99.69
600 microns	2.34	.234	.544	99.45
300 microns	115.6	11.5	12.11	87.89
150 microns	770.5	77.05	89.16	10.84

4.3 Mechanical Properties

4.3.1 Compressive Strength

Compressive strength of concrete provides an idea of characteristics of concrete. Concreting is done properly or not can be judged by doing this single test. Compressive strength of concrete mainly depends on several factors i.e. cement strength, water-cement ratio, quality of materials used in concrete etc. Concrete mixtures containing waste foundry sand exhibited almost same strength and strength of concrete increased with the increase of waste foundry sand content up to certain amount shown in fig.4.1. At the curing age of 7 days, the decrement in strength was 4.5% for concrete mixtures M-7 (15%) and M-6 (12.5%) exhibited almost same strength but marginal decreases up to 0.13%, Whereas the increment in strength was 3.65%, 8.6%, 6.17% and 3.3% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%)and M-5 (10%) as compared to control mix without waste foundry sand M-1 (0%) i.e. 31.23 MPa.

At the curing age of 28 days, the marginal increment in strength was 0.71% for concrete mixture M-6 (12.5%) and the decrease in strength was 3.67% for concrete mixture M-7 (15%), whereas the increment in strength was 3.93%, 9.3%, 6.54% and 5.7% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5) and M-5 (10%) as compare to control mix M-1 (0%) i.e. 42.83 MPa. At the curing age of 56 days, the increment in strength was 4.87%, 9.45%, 7.8%, 6.27% and 1.27%, for concrete mixtures M-2 (2.5%), M-3 (5%), M-4 (7.5), M-5 (10%) and M-6 (12.5%), whereas decrease in strength was observed up to 3.52% for concrete mixture M-7

(15%) as compare to control mix i.e. 44.37 MPa. The compressive strength variations in values can easily by observed by fig 4.1. It was observed that the compressive strength values for M-3 (5%) of inclusion at all curing ages exhibited higher strength as compared to control mix M-1 (0%) and there was a systematic decrease in strength after 5% inclusion of foundry sand for all ages in concrete.

Table 4.7 Percentage of increment and decrement of compressive strength as compare to control mix

WFS %	**7 days**	**28 days**	**56 days**
0			
2.5	3.65%	3.93%	4.87%
5	8.6%	9.3%	9.45%
7.5	6.17%	6.54%	7.8%
10	3.3%	5.7%	6.27%
12.5	-0.13%	0.71%	1.27%
15	-4.5%	-3.67%	-3.52%

The increment in compressive strength is due to the presence of fine particles in waste foundry sand that acts as good packing material, and this ultimately results in the formation of denser concrete mix[87]. The presence of fine particles fills the voids and decreases the pores in components of concrete results in dense matrix, and further results in decreasing of the electrical conductance of concrete[23]. The WFS contains silica content in high amount which helps in the formation of C-H-S gel and this is due to the packing behavior of matrix particle[58]. The decrement in strength after 5% replacement level of WFS is due to increment in surface area of particles which are fine in size led to decrease the water cement gel in matrix and further the binding process of fine and coarse aggregates does not carried out in a correct manner. The maximum strength was observed at 5% replacement level of WFS at all ages, as clear from Fig. Similar results and observations were reported by Siddique et al.[12], Guney et al.[26], Prabhu et al.[28], Singh & Siddique[34], Basar & Aksoy[33], Siddique et al.[40], Bilal et al.[58].

Siddique et al.[12] investigated that there is an increment in both type of grade i.e. (M20 an M30) in concrete with increase in replacement level of waste foundry sand. There was a increment in strength i.e. 34.4 MPa and 43.3 MPa at 10% WFS inclusion in concrete at both grades as compared to control mix i.e. 30 MPa and 40 MPa at 28 days of curing age for both grades of concrete. Author observed that there was an increase in compressive strength as the curing age increases of concrete. Guney et al.[26] replaced waste foundry sand with fine aggregates at several percentages (0%, 5%, 10% and 15%) in concrete. Author reported that there was a marginal decrement in compressive strength and carries almost similar results at 10% of WFS inclusion in concrete i.e. 60.1 MPa as compared to control mix at 28 days of curing age i.e. 60.3 MPa. Author observed that the compressive strength increases with the increase of curing age. Prabhu et al.[28] evaluated the effect of waste foundry sand in concrete. Author reported that 10% of WFS inclusion in concrete carries almost same strength and have marginal increment i.e. 33. 24 MPa as compared to control mix i.e. 33.14 MPa. After 10% inclusion of WFS there was a systematic decrease in compressive strength and author observed that there was increase in compressive strength as the curing age of sample increase in concrete.

Singh & Siddique[34] performed various test by replacing WFS at several percentages i.e. (5%, 10%, 15% and 20%) with natural sand in concrete. Author reported that the 10% of inclusion in concrete exhibited increment of 8.3% and as the percentage increases of WFS it was increases up to 13.5% as compared to control mix at 28 days of curing age. Author observed that the main cause of strength decrement after certain level of increment was because of reduction in surface area of matrix in water-cement gel due to witch fine coarse binding process in concrete does not take place properly[12],[24],[34]. Basar & Aksoy[33] reported that 10% WFS inclusion in concrete reported almost similar results and there was a marginal increase in strength i.e. 44.1 MPa as compared to control mix at the curing age of 28 days i.e. 43.2 MPa. After 10% of WFS inclusion in concrete there was a systematic decrease in compressive strength. Author observed that with the increase in curing age there was increment in compressive strength.

Siddique et al.[40] performed various tests by replacing WFS with natural sand in concrete at several percentages level i.e. (10%, 20% and 30%) and examined the various effects of WFS in concrete. Author reported that there was a increment in strength of 4.2% at 10% WFS inclusion in concrete and as the percentage goes on increasing there was an increment in strength up to 9.8% at 30% of WFS inclusion in concrete as compared to control mix at the curing age for 28 day i.e. 28.5 MPa. Bilal et al.[58] studied the effect of WFS in concrete by replacing WFS with fine aggregate at several percentages i.e.(10%, 20%, 30% and 40%) in concrete. Author observed that at 10% inclusion of WFS in concrete there was marginal increment in the strength i.e. 2.67% and as the percentage goes on increasing the strength also increases up to 30% of inclusion i.e. 7.82% as compared to control mix at 28 days of curing age i.e. 28.1 MPa.

Table 4.8 Compressive strength versus age

WFS %	7 days (MPa)	28 days (MPa)	56 days (MPa)
0	31.23	42.83	44.37
2.5	32.37	44.51	46.53
5	33.89	46.81	48.56
7.5	33.16	45.63	47.83
10	32.26	45.25	47.15
12.5	31.19	43.16	44.93
15	29.85	41.26	42.81

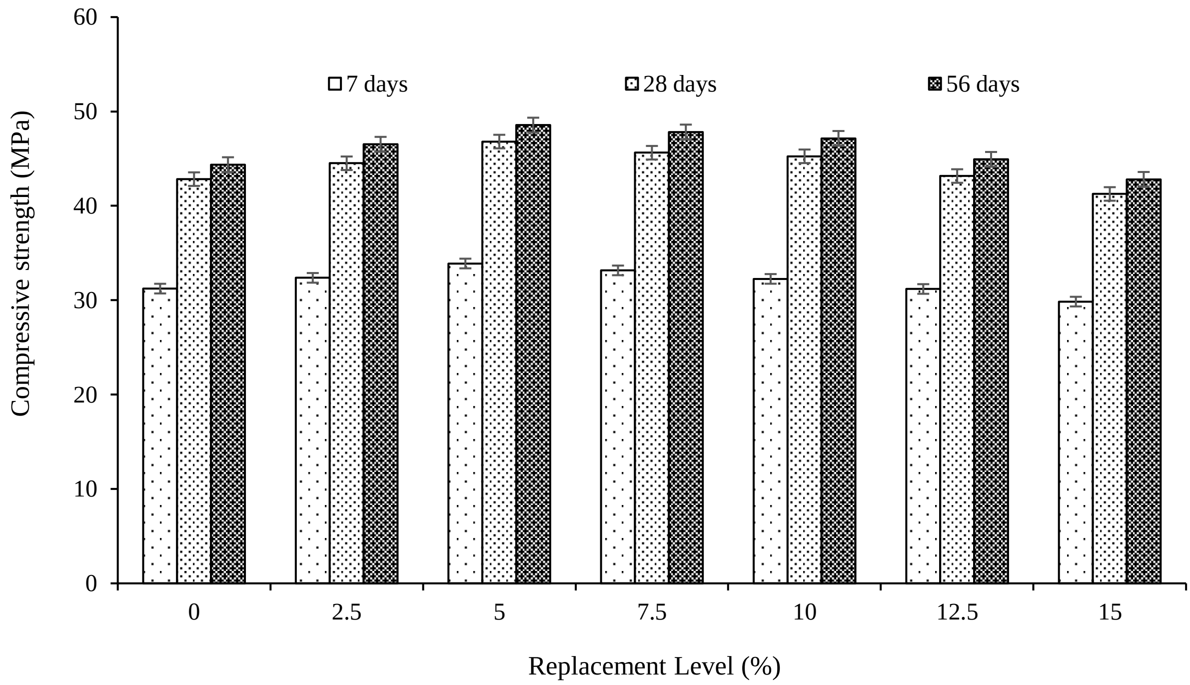

Fig 4.1 Compressive strength versus age

4.3.2 Splitting Tensile Strength

The tensile strength is one of the basic and essential properties of concrete which greatly influence the size of cracking in structure. The concrete is brittle in nature so it is very weak in tension due to which it cannot resist direct tension. So, when tensile forces exceed the tensile strength of concrete develops cracks in the concrete members. Splitting tensile strength increases with the increase in the replacement level of waste foundry sand up to certain amount at all curing ages shown in fig no.4.2. At curing age of 7 days, the increment in strength was 4.46%, 10.8%, 7.97% and 3.51% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%) and

M-5 (10%), Whereas decrement in strength was 4.78% for concrete mixture M-7 (15%) and control mixture M-7 (12.5%) exhibited almost same strength i.e. 1.6% as compare to control mix M-1 (0%) i.e. 3.24 MPa.

Table 4.9 Percentage of increment and decrement of splitting tensile strength as compare to control mix.

WFS %	7 days	28 days	56 days
0			
2.5	4.46%	4.8%	5.31%
5	10.8%	11.37%	12.84%
7.5	7.97%	8.34%	8.63%
10	3.51%	4.05%	4.21%
12.5	1.6%	2.53%	3.32%
15	-4.78%	-3.79%	-3.54%

At curing age of 28 days, the increment in strength was 4.8%, 11.37%, 8.34%, 4.05% and 2.53% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%), M-5 (10%) and M-6 (12.5%), whereas decrement in strength was observed for concrete mixture M-7 (15%) was 3.79% as compared to control mix M-1 (0%) i.e. 3.96 MPa. At curing age of 56 days, the increment in strength was 5.31%, 12.84%, 8.63%, 4.21% and 3.32% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%), M-5 (10%) and M-6 (12.5%), whereas decrement in strength was observed for concrete mixture M-7 (15%) was 3.54% as compare to M-1 (0%) i.e. 4.52 MPa. The splitting tensile strength variations of values can be observed from fig no.4.2. The increment in strength was observed up to 5% of replacement level of WFS and after that there was a systematic decrease in strength at all curing ages. The maximum strength was observed at 5% inclusion of WFS in concrete. Similar results and observations were reported by Siddique et al.[12], Guney at el.[26], Prabhu et al.[28], Siddique et al.[34], Siddique et al.[40], Bilal et al.[58].

Siddique et al.[12] reported that there was an increment in strength i.e. 3.7 MPa and 4.38 MPa at 10% WFS inclusion in concrete at both grades as compared to control mix i.e. 3.42 MPa and 4.32 MPa at 28 days of curing age for both grades of concrete. Author observed that there was an increase in split tensile strength as the curing age increases of concrete. Guney at el.[26] reported that there was increment in split tensile strength and carries maximum strength at 10% of WFS inclusion in concrete i.e. 3.91 MPa as compared to control mix at 28 days of curing age i.e. 3.57 MPa. Author observed that the split tensile strength increases with the increase of curing age.

Prabhu et al.[28] reported that 10% of WFS inclusion in concrete carries almost same strength and have marginal decrement i.e. 2.612 MPa as compared to control mix i.e. 2.765 MPa. After 10% inclusion of WFS there was a systematic decrease in splitting tensile strength and author observed that there was increase in splitting tensile strength as the curing age of sample increase in concrete. Singh & Siddique[34] reported that the 10% of inclusion in concrete exhibited increment i.e. 4.64 MPa and as the percentage increases of WFS it was increases from 3.55%-10.40% as compared to control mix 4.21 MPa at 28 days of curing age.

Siddique et al.[40] performed various test by partially replacing WFS with fine aggregates at different percentages. The author reported that there is an increment in strength up to 9% from 10% to 30% inclusion of WFS as compared to control mix at 28 days of curing ages i.e. 2.75 MPa. Bilal et al.[58] observed that at 10% inclusion of WFS in concrete there was marginal increment in the strength i.e. 3.38% and as the percentage goes on increasing the strength also increases up to 30% of inclusion i.e. 9.87% as compared to control mix at 28 days of curing age i.e. 3.28 MPa.

Table 4.10 Splitting tensile strength versus age

WFS %	**7 days (MPa)**	**28 days (MPa)**	**56 days (MPa)**
0	3.14	3.96	4.52
2.5	3.28	4.15	4.76
5	3.48	4.41	5.1
7.5	3.39	4.29	4.91
10	3.25	4.12	4.71
12.5	3.19	4.06	4.67
15	2.99	3.81	4.36

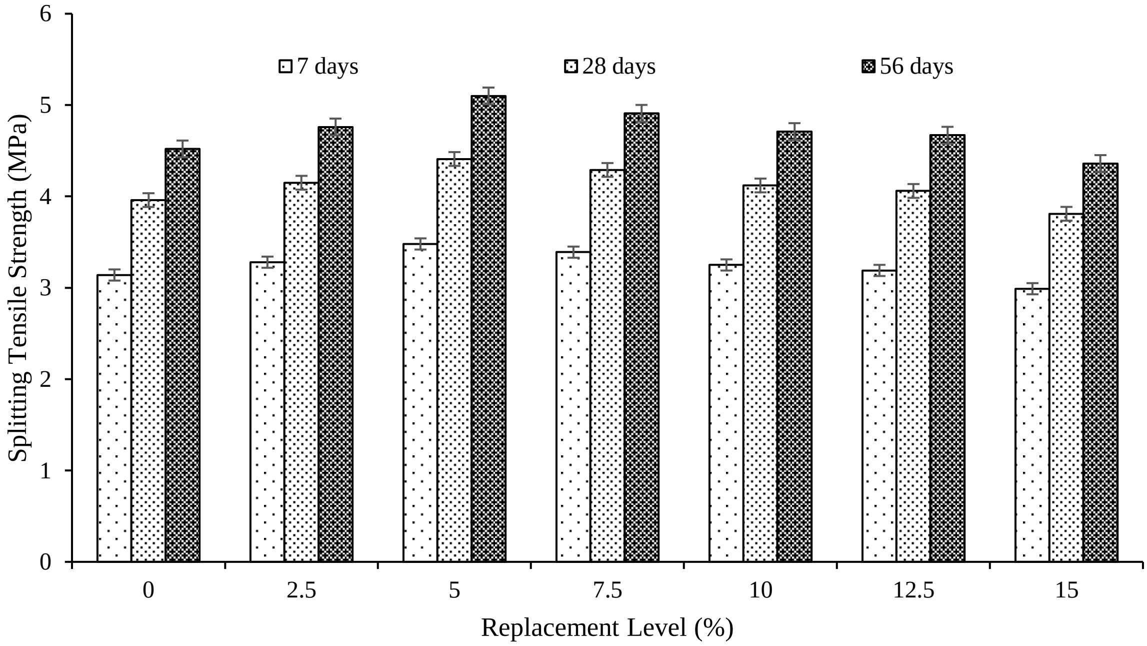

Fig 4.2 Splitting tensile strength versus age

4.3.3 Flexural strength

Flexural strength is also known as bend strength, transverse of rupture or modulus of rupture, is a mechanical parameter for material i.e. brittle in nature and is define as an ability of materials to resist deformation under a several amount of load. Flexural strength is a basic mechanical property is co related with compressive strength and splitting tensile strength. Flexural strength increases with the increase in the replacement level of waste foundry sand up to certain amount shown in fig 4.3. At curing age of 7 days, the increment of strength was 3.46%, 10.09%, 7.21%, 4.33% and 3.18% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%), M-5 (10%) and M-6 (12.5%), whereas the decrement in strength was 4.61% for concrete mixture M-7 (15%) as compared to control mix M-1 (0%) i.e. 3.47 MPa.

Table 4.11 Percentage of increment and decrement of flexural strength as compare to control mix

WFS %	7 days	28 days	56 days
0			
2.5	3.46%	3.81%	4.92%
5	10.09%	12.27%	13.26%
7.5	7.21%	8.66%	10.6%
10	4.33%	5.29%	7.58%
12.5	3.18%	3.39%	4.93%
15	-4.61%	-5.08%	-5.69%

At curing age of 28 days, the increment of strength was 3.81%, 12.27%, 8.66%, 5.29% and 3.39% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%), M-5 (10%) and M-6 (12.5%), whereas the decrement in strength was 5.08% for concrete mixture M-7 (15%) as compared to control mix M-1 (0%) i.e. 4.73 MPa. At curing age of 56 days, the increment of strength was 4.92%, 13.26, 10.26%, 7.58% and 4.93% for concrete mixture M-2 (2.5%), M-3 (5%), M-4 (7.5%), M-5 (10%) and M-6 (12.5%), whereas the decrement in strength was 5.69% for concrete mixture M-7 (15%) as compared to control mix M-1 (0%) i.e. 5.28 MPa. The flexural strength variations of values can be observed from fig 1.3. The increment in strength was observed up to 5% of replacement level of WFS and after that there was a systematic decrease in strength at all curing ages. The maximum strength was observed at 5% inclusion of WFS in concrete. Similar results and observations were reported by Prabhu et al.[28], Bilal et al.[58].

Prabhu et al.[28] performed several tests and concluded that there was a systematic decrease in flexural strength. The 10% inclusion of WFS and 20% inclusion of WFS caries almost same strength i.e. 3.986 MPa and 3.988 MPa as compare to control mix at 28 days of curing age i.e. 4.089 MPa but these values of mixes shows less strength as compare to control mix. Bilal et al.[58] observed that at 10% inclusion of WFS in concrete there was marginal increment in the strength i.e. 3.12% and as the percentage goes on increasing the strength also increases up to 30% of inclusion i.e. 10.35% as compared to control mix at 28 days of curing age i.e. 6.15 MPa.

Table 4.12 Flexural strength versus age

WFS %	7 days (MPa)	28 days (MPa)	56 days (MPa)
0	3.47	4.73	5.28
2.5	3.59	4.91	5.54
5	3.82	5.31	5.98
7.5	3.72	5.14	5.84
10	3.62	4.98	5.68
12.5	3.58	4.89	5.54
15	3.31	4.49	4.98

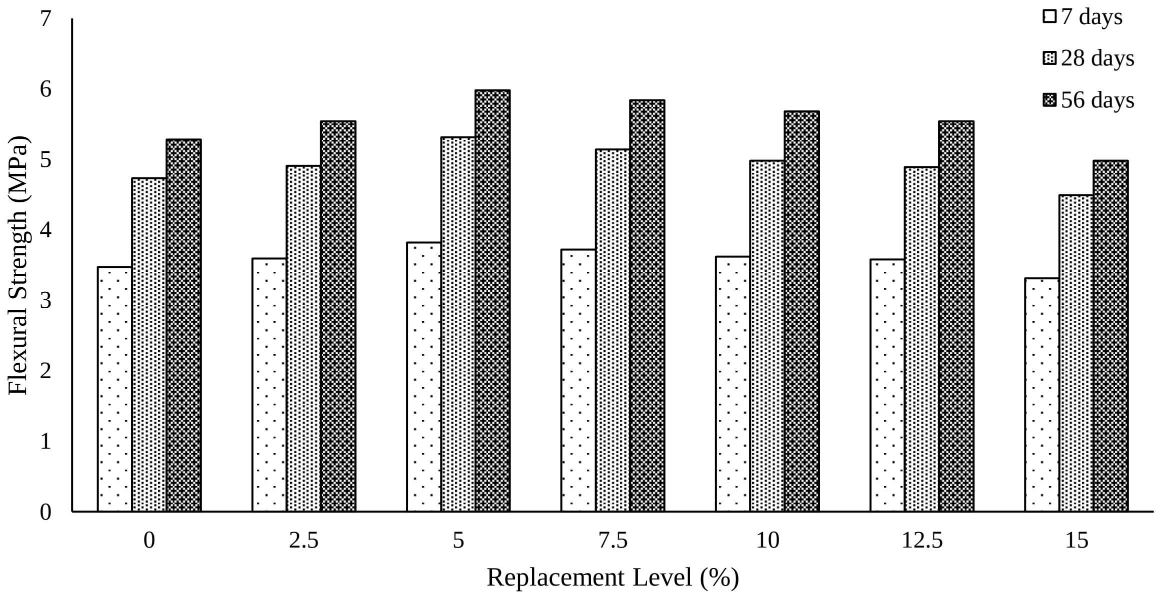

Fig 4.3 Flexural strength versus age

4.4 Durability property

4.4.1 Sulphate Resistance Test

The sulphate resistance test was conducted on specimens of size 150x150x150 mm cubes. The cubes were properly casted and cured for 28 days in water. After 28 days of curing, cubes were immersed in magnesium sulphate solution and further compressive strength test was done for 14 and 28 days of curing ages. The reduction and increment or any change in strength are given in Table 4.12.

Table 4.13 Compressive strength of specimens after immersion in solution of $MgSo_4$

Mix	42 days compressive strength (MPa)		56 days compressive strength (MPa)	
	Controlled (42 days)	**Immersed (14 days)**	**Controlled (56 days)**	**Immersed (28 days)**
1	43.25	45.26	44.37	45.74
2	45.28	46.94	46.53	47.86
3	47.37	49.94	48.56	50.31
4	46.41	50.38	47.83	51.62
5	45.87	51.08	47.15	51.73
6	43.73	42.65	44.93	43.37
7	41.69	38.44	42.81	38.7

It was observed that up to M-5 (10%) of WFS in concrete shows systematic increment in strength i.e. 45.74 MPa – 51.73 MPa and after that there is decrease in strength for M-6 (12.5%) and M-7 (15%) i.e. 43.37 MPa and 38.7 MPa at 28 days of curing age shown in fig.4.4. The increment in strength is because of the waste foundry sand that increases the strength of magnesium sulphate due to presence of traces of Sulphur (SO_3) in it which causes deterioration in concrete and enhances the ettringite formation[59],[76]–[78]. The fig no. shows the compressive strength results of specimens after immersion in solution of $MgSo_4$. Similar results and observations were reported by Siddique & Sandhu[65], Prabhu et al.[59].

Siddique & Sandhu[65] investigated on the concrete containing WFS first cured for 28 days and then immersed in 50g/l $MgSo_4$ for several days of curing. Author reported that 10% inclusion of WFS in concrete showed more strength as compare to all percentages in concrete for all curing ages. If concrete samples immersed for a long time it affects the strength properties of concrete. Prabhu et al.[59] reported that as the curing age of concrete increased containing WFS and immersed in $MgSO_4$ and $NaSO_4$ solution there is a decrease in strength. Author observed that there was a reduction in compressive strength at 180 days up to 6.18% and at 360 days up to 13.14%. The increment in strength was because of the waste foundry sand that increases the strength of magnesium sulphate due to presence of traces of Sulphur (SO_3) in it which causes deterioration in concrete and enhances the ettringite formation[59],[76]–[78].

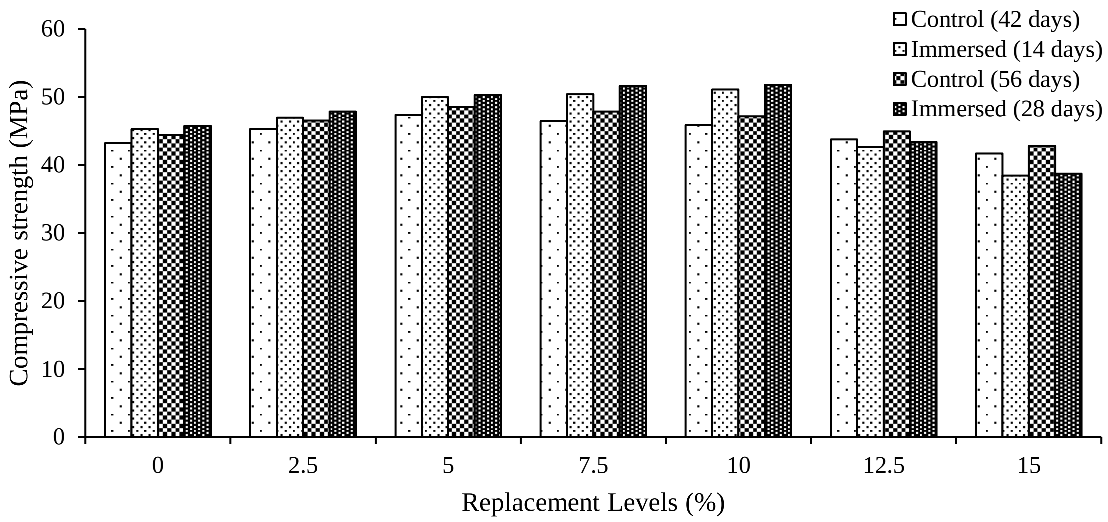

Fig 4.4 Compressive strength of specimens after immersion in solution of $MgSo_4$

CHAPTER 5
CONCLUSION

5.1 General

The present investigation is on the study of effective use of waste foundry sand as a partial replacement by regular sand as a fine aggregate in concrete. Mechanical i.e. (compressive strength, splitting tensile strength and flexural strength) and durability properties i.e. sulphate resistance) of concrete were checked by replacing waste foundry sand at several percentages i.e. (0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%) with natural sand in concrete. Test results in this investigation indicates that industrial by-product i.e. waste foundry sand is suitable and can be used in concrete as a substitute for regular sand in concrete

5.2 Conclusion

The reuse of waste foundry sand as a substitute with fine aggregates for production of concrete up to certain percentage in this research is based on to evaluate the mechanical and durability properties of concrete. The extensive tests are carried out on seven mix and following conclusion based on these tests have been made.

a) The inclusion of waste foundry sand with fine aggregates in concrete enhance the strength properties with increasing content of WFS up to certain replacement level and further the strength properties also improved with the increase in curing age.

b) Compressive strength of concrete increased from 3.93%–9.3% and after that there is a systematic decrease in strength, splitting tensile strength of concrete increased from 4.8% - 11.37% and after that there is systematic decrease in strength, flexural strength of concrete increased from 3.81%-12.27% and after that there is systematic decrease in strength at 28 day of curing age.

c) The maximum strength was observed at 5% WFS of inclusion with fine aggregates in concrete at all curing ages in mechanical properties i.e. (compressive strength, splitting tensile strength and flexural strength).The increment in strength can be observed because WFS contains silica content in high amount which helps in the formation of C-S-H gel and this is due to the packing behavior of matrix particles.

d) The sulphate resistance test was done on concrete mixture containing waste foundry sand and observed that 10% of WFS replacement level gives the maximum compressive strength value i.e. 51.73 MPa for 28 days of curing age. The increment in strength is because of the waste foundry sand that increases the strength of magnesium sulphate due to presence of traces of Sulphur (SO_3) in it which causes deterioration in concrete and enhances the ettringite formation.

e) The maximum values were observed for 5% of WFS replacement level containing concrete for all tests of mechanical properties and 10% of WFS replacement level in concrete level gives the maximum value for the sulphate resistance test in concrete.
f) From following observation, it was observed that 10% of waste foundry sand replacement level can be successfully used to make concrete and in various applications of concrete like concrete paver blocks, whereas beyond this replacement level is not beneficial.

5.3 Limitations of Study

From our investigation we have found that there are few limitations associated with the addition of waste foundry sand in concrete. In case of mechanical strength, the concrete containing waste foundry sand up to 12.5 % shows increment in strength after that there was a decrement in strength because of presence of fine particles in WFS reduces the surface area leads to affect the water-cement gel matrix due to which binding process do not occurs properly in concrete and further inclusion of WFS in concrete can negatively affects the mechanical property of concrete. In case of durability property, the concrete containing waste foundry sand up to 10 % shows increment in strength after that there was a decrement in strength and further inclusion of WFS in more amount can negatively affects the durability property of concrete

5.4 Future Scope

The using waste in a proper manner is a big problem for the government and country which is increasing day by day. The waste foundry sand can be used beneficially in concrete up to certain amount without causing any negative affect to the properties. More research should be conducted in usage of its amount in concrete without any negative affect. The concrete is weak in tension and strong in compression so using waste foundry sand increases it tensile properties and this property can be further studies in detail to enhance tensile strength property in concrete. In this study, the sulphate resistance test was done to check its durability and results shows that we can use it in several places were simultaneously acid rain occurs, ground were construction i.e. (concrete paver blocks, foundation of concrete) are constructed holds some chemicals as in soil can that negatively affect the strength of concrete containing waste foundry sand. Furthermore, the study of sulphate resistance can be done in more detail so to enhance the durability property of concrete containing waste foundry sand.

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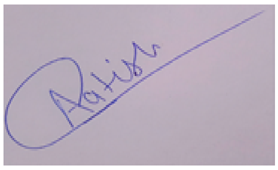

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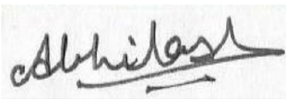

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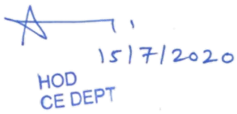

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