

**PROPERTIES OF MORTAR INCORPORATING WASTE
FOUNDRY SAND**

Thesis submitted
In partial fulfillment of the requirement for the
Award of the degree of

**MASTER OF ENGINEERING
IN
CIVIL ENGINEERING
(STRUCTURES)**

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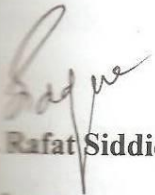


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CERTIFICATE

This is to certify that the thesis entitled "PROPERTIES OF MORTAR INCORPORATING WASTE FOUNDRY SAND", being submitted by Mr. Alok Khanduri in partial fulfillment of requirements, for the award of degree of MASTER OF ENGINEERING in CIVIL (STRUCTURES) ENGINEERING of THAPAR UNIVERSITY, PATIALA, is a bonafide work carried out by him under my supervision and guidance.

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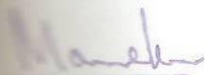


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ABSTRACT

Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed “foundry sand.” Foundry sand production is nearly 6 to 10 million tons annually. Like many waste products, foundry sand has beneficial applications to other industries.

Foundry sand consists primarily of silica sand, coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins) and dust. Foundry sand can be used in concrete to improve its strength and other durability factors. Foundry Sand can be used as a partial replacement of cement or as a partial replacement of fine aggregates or total replacement of fine aggregate and as supplementary addition to achieve different properties of concrete.

In the present study, effect of foundry sand as fine aggregate replacement on the compressive strength, Porosity, Sulphate attack & XRD of cement mortar having mix proportions of 1:3 was investigated. Fine aggregates were replaced with seven percentages of foundry sand. The percentages of replacements were 0, 10, 20, 30, 40, 60 & 100 % by weight of fine aggregate. Tests were performed for compressive strength, Porosity, Sulphate attack & XRD tests for all replacement levels of foundry sand at different curing periods (28-days & 90-days).

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CHAPTER 1

INTRODUCTION

1.1 General

Foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and nonferrous metal casting industries, where sand has been used for centuries as a molding material because of its thermal conductivity. It is a by-product from the production of both ferrous and non-ferrous metal castings.

The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. In modern foundry practice, sand is typically recycled and reused through many production cycles. Industry estimates that approximately 100 million tons of sand is used in production annually of that 6 - 10 million tons are discarded annually and are available to be recycled into other products and in industry. The automotive industries and its parts are the major generators of foundry sand. Foundries purchase high quality size-specific silica sands for use in their molding and casting operations.

The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. The sands form the outer shape of the mold cavity. These sands normally rely upon a small amount of bentonite clay to act as the binder material. Chemical binders are also used to create sand “cores”. Depending upon the geometry of the casting, sands cores are inserted into the mold cavity to form internal passages for the molten metal. Once the metal has solidified, the casting is separated from the molding and core sands in the shakeout process. In the casting process, molding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. At that point, the old sand is displaced from the cycle as by-product, new sand is introduced, and the cycle begins again. A schematic of the flow of sands through a typical foundry is shown in Fig.1.1. Although there are other casting methods used, including die casting and permanent mold casting, sand casting is by far most prevalent mold casting technique. Sand is used in two different ways in metal castings as a molding material, which focuses the external shape of the cast part and as cores that form internal void spaces in products such as engine blocks. Since sand grains do not naturally adhere to each other so

binders must be introduced to cause the sand to stick together and holds its shape during the introduction of molten metal into mold and cooling of casting.

1.2 Manufacturing of Foundry Sand

Foundry sand is produced by five different foundry classes. The ferrous foundries (gray iron, ductile iron and steel) produce the most sand. Aluminum, copper, brass and bronze produce the rest. The 3,000 foundries in the United States generate 6 million to 10 million tons of foundry sand per year. While the sand is typically used multiple times within the foundry before it becomes a by-product, only 10 percent of the foundry sand was reused elsewhere outside of the foundry industry in 2001. The sands from the brass, bronze and copper foundries are generally not reused. While exact numbers are not available, the best estimate is that approximately 10 million tons of foundry sand can beneficially be used annually.

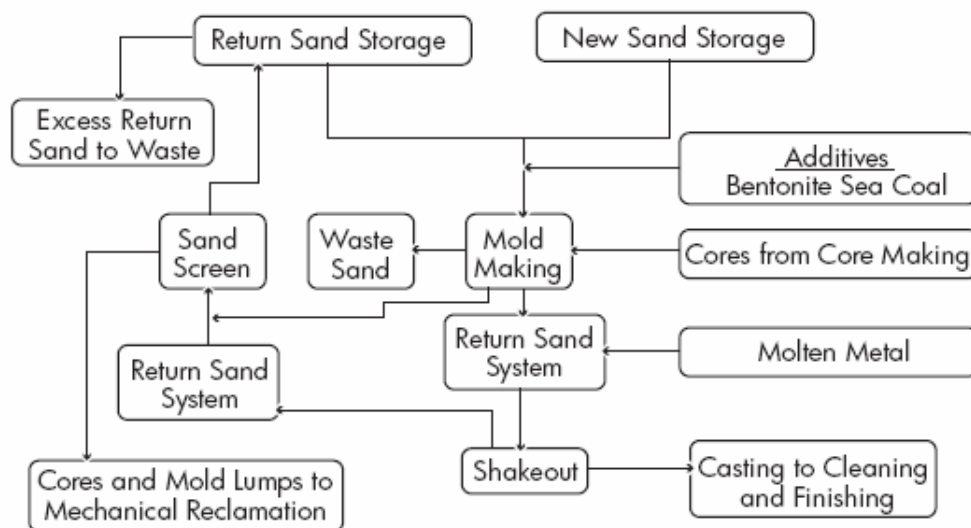


Fig. 1.1: How sand is reused and becomes foundry sand

1.3 Types of Foundry Sands

Classification of foundry sands depends upon the type of binder systems used in metal casting. Two types of binder systems are generally used, and on the basis of that foundry sands are categorized as: clay-bonded sands (green sand) and chemically-bonded sands. Both types of sands are suitable for beneficial use but they have different physical and environmental characteristics.

- Green sand molds are used to produce about 90% of casting volume in the U.S. Green sand is composed of naturally occurring materials which are blended together; high quality silica sand (85-95%), bentonite clay (4-10%) as a binder, a carbonaceous additive (2-10%) to improve the casting surface finish and water (2-5%). Green sand is the most commonly used recycled foundry sand for beneficial reuse. It is black in colour, due to carbon content and adheres together due to clay and water.
- Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mold making. Chemically bonded sand consists of 93–99% silica and 1–3% chemical binder. Silica sand is thoroughly mixed with the chemicals. Most chemical binder systems consist of an organic binder that is activated by a catalyst although some systems use inorganic binders. Chemically bonded sands are generally light in colour and in texture than clay bonded sands. There are various types of chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxyresins, furfuryl alcohol, and sodium silicates. Chemically bonded sands are generally light in colour and in texture than clay bonded sands.

1.4 Material Properties

1.4.1 Physical Characteristics of Foundry Sand

Foundry sand is typically sub-angular to rounded in shape. After being used in the foundry process, a significant number of sand agglomerations form. When these are broken down, the shape of the individual sand grains is apparent.



Fig.1.2: Unprocessed Foundry Sand

Green sands are typically black, or gray, not green chemically bonded sand is typically a medium tan or off-white colour Figs.1.2 & 1.3 shows the unprocessed foundry sand and green sand respectively.



Fig.1.3: Green Sands from a gray iron Industry

1.4.2 Physical Properties

Typical physical properties of spent foundry sand from green sand systems are given in Table-1.1. The grain size distribution of spent foundry sand is very uniform, with approximately 85 to 95 percent of the material between 0.6 mm and 0.15 mm (No. 30 and No. 100) sieve sizes. 5 to 12 percent of foundry sand can be expected to be smaller than 0.075 mm (No. 200 sieve). The particle shape is typically sub angular to round. Waste foundry sand gradations have been found to be too fine to satisfy some specifications for fine aggregate.

Spent foundry sand has low absorption and is non-plastic. Reported values of absorption were found to vary widely, which can also be attributed to the presence of binders and additives. The content of organic impurities (particularly from sea coal binder systems) can vary widely and can be quite high. This may preclude its use in applications where organic impurities could be important (e.g., Portland cement concrete aggregate). The specific gravity of foundry sand has been found to vary from 2.39 to 2.55. This variability has been attributed to the variability in fines and additive contents in different samples. In general, foundry sands are dry, with moisture contents less than 2 percent. A large fraction of clay lumps and friable particles have been reported, which are attributed to the lumps associated with the molded sand, which are easily disintegrated in the test procedure. The variation in permeability, listed in Table-1.1, is a direct result of the fraction of fines in the samples collected.

Table-1.1: Typical physical properties of spent green foundry sand

Property	Results	Test Methods
Specific Gravity	2.39- 2.55	ASTM D854
Bulk Relative Density, Kg/m ³ (lb/ft ³)	2589 (160)	ASTMC48/ AASTHO T84
Absorption %	0.45	ASTM C128
Moisture Content %	0.1- 10.1	ASTM D2216
Clay Lumps & Friable Particles	1- 44	ASTM C142/ AASTHO T112
Coefficient of Permeability (Cm/Sec.)	10 ⁻³ - 10 ⁻⁶	AASTHO T215/ ASTM D2434
Plastic Limit/ Plastic Index	Non-plastic	AASTHO T90/ ASTM D4318

The quality of foundry sand can be quantified by its durability and soundness, chemical composition, and variability. Various aspects of foundry sand production influence these three characteristics. Durability/Soundness of foundry sand is important to ensure the long-term performance of civil engineering applications. Durability of the foundry sand depends on how the sand was used at the foundry. Successive molding can cause the foundry sand to weaken due to temperature shock. At later stages of mold use, this can lead to the accelerated deterioration of the original sand particles. However, in civil engineering uses, the foundry sand will not normally be subjected to such severe conditions. In geotechnical applications, foundry sand often demonstrates high durability.

1.4.3 Chemical Composition

Chemical Composition of the foundry sand relates directly to the metal molded at the foundry. This determines the binder that was used, as well as the combustible additives.

Typically, there is some variation in the foundry sand chemical composition from foundry to foundry. Sands produced by a single foundry, however, will not likely show significant variation over time. Moreover, blended sands produced by consortia of foundries often produce consistent sands. The chemical composition of the foundry sand can impact its performance. Spent foundry sand consists primarily of silica sand, coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins) and dust.

Silica sand is hydrophilic and consequently attracts water to its surface. This property could lead to moisture-accelerated damage and associated stripping problems in an asphalt pavement. Antistripping additives may be required to counteract such problems. Depending on the binder and type of metal cast, the pH of spent foundry sand can vary from approximately 4 to 8. It has been reported that some spent foundry sands can be corrosive to metals. Because of the presence of phenols in foundry sand, there is some concern that precipitation percolating through stockpiles could mobilize leach able fractions, resulting in phenol discharges into surface or ground water supplies. Foundry sand sources and stockpiles must be monitored to assess the need to establish controls for potential phenol discharges.

1.4.4 Mechanical Properties

Typical mechanical properties of spent foundry sand are listed in Table–1.2. Spent foundry sand has good durability characteristics as measured by low Micro-Deval abrasion and magnesium sulfate soundness loss tests. The Micro-Deval abrasion test is an attrition/abrasion test where a sample of the fine aggregate is placed in a stainless steel jar with water and steel bearings and rotated at 100 rpm for 15 minutes. The percent loss has been determined to correlate very well with magnesium sulfate soundness and other physical properties. Recent studies have reported relatively high soundness loss, which is attributed to samples of bound sand loss and not a breakdown of individual sand particles. The angle of shearing resistance (friction angle) of foundry sand has been reported to be in the range of 33 to 40 degrees, which is comparable to that of conventional sands.

Table 1.2- Typical Mechanical Properties of Spent Foundry Sand

Property	Results	Test Methods
Micro- Devil Abrasion Loss %	< 2	-
Magnesium sulphate Soundness Loss %	5- 15 6- 47	ASTM C88
Friction Angle (deg)	33- 40	-
California Bearing Ratio, %	4- 20	ASTM D1883

1.5 Application of Foundry Sand

- Embankments
- Barrier layers Construction
- Flowable fills
- Roadway Construction
- Soil reinforcement
- Hot mix asphalt
- Portland Cement manufacturing
- Rock wool manufacturing
- Fibre glass manufacturing

- Landfill cover/ barriers

1.6 Current Management Options

1.6.1 Handling of Foundry sand

Foundry sand is most often collected and stockpiled outside of the foundries, exposed to the environment. Prior to use in an engineering application, the majority of foundry sand is:

- Collected in closed trucks and transported to a central collection facility;
- Processed, screened, and sometimes crushed to reduce the size of residual core sand pieces. Other objectionable material, such as metals, is removed.

1.6.2 Recycling

In typical foundry processes, sand from collapsed molds or cores can be reclaimed and reused. Some new sand and binder is typically added to maintain the quality of the casting and to make up for sand lost during normal operations. Five different foundry classes produce foundry sand. The ferrous foundries (gray iron, ductile iron and steel) produce the most sand and the rest is produced by Aluminium, copper, brass and bronze. The 3,000 foundries in the United States generate 6 million to 10 million tons of foundry sand per year. While the sand is typically used multiple times within the foundry before it becomes a byproduct, only 10 percent of the foundry sand was reused elsewhere outside of the foundry industry in 2001. The sands from the brass, bronze and copper foundries are generally not reused. While exact numbers are not available, the best estimate is that approximately 10 million tons of foundry sand can beneficially be used annually. Fig.1.3 shows how the sand is reused and becomes foundry sand.

Little information is available regarding the amount of foundry sand that is used for purposes other than in-plant reclamation, but spent foundry sand has been used as a fine aggregate substitute in construction applications and as kiln feed in the manufacture of Portland cement.

1.6.3 Disposal

Most of the spent foundry sand from green sand operations is land filled, sometimes being used as a supplemental cover.

1.6.4 Foundry Sand Economics

The success of using foundry sand depends upon economics. The bottom line issues are cost, availability of the foundry sand and availability of similar natural aggregates in the region. If these issues can be successfully resolved, the competitiveness of using foundry sand will increase for the foundries and for the end users of the sand. This is true of any recycled material.

CHAPTER 2

LITERATURE REVIEW

In this chapter the research work concerning to the various application and methods used for testing of the concrete made by foundry sand are discussed. This chapter gives a comprehensive review of the work carried out by various researchers in the field of using foundry sand in concrete as partial or full replacement of fine aggregates.

2.1 Properties of Concrete

2.1.1 Compressive strength

Siddique et al. (2009), studied the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS). The physical properties of Used foundry sand & fine sand are shown in Table. Fine aggregate was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. Compressive strength of concrete mixtures made with and without used-foundry sand (UFS) was determined at 7, 28, 56, 91, and 365 days of curing. For this One hundred and fifty mm concrete cubes were cast for compressive strength. The physical properties & Mixture proportion are given in Table 2.1 & 2.2.

Table 2.1: Physical properties of used-foundry sand (UFS) and regular sand, (Siddique et al. (2009))

Property	Used Foundry Sand (UFS)	Regular Sand (fine aggregate)	ASTMC 33
Specific gravity	2.2	2.68	-
Unit Weight (Kg/m ³)	1520	1750	-
Absorption (%)	1.3	0.86	-
Fineness modulus	1.6	2.5	2.3- 3.1
Clay lumps & friable particles (%)	0.9	-	3 max
Materials finer than 75 μm (%)	8	0.8	3 max

Table 2.2: Mixture proportions of concrete mixtures containing UFS, (Siddique et al. (2009))

Mixture No.	M 1	M 2	M 3	M 4
Cement (Kg/m ³)	372	372	372	372
Foundry Sand (%)	0	10	20	30
Foundry Sand (Kg/m ³)	0	54	108	162
Water (Kg/m ³)	186	186	186	186
W/C	0.5	0.5	0.5	0.5
Sand SSD (Kg/m ³)	539	485	431	377
Coarse aggregate (10 mm) (Kg/m ³)	410	410	410	410
Coarse aggregate (20 mm) (Kg/m ³)	819	819	819	819
Super plasticizer (l/m ³)	4.5	5.9	5.9	5.9
Slump (mm)	90	85	85	80
Air content (%)	4.2	4.5	4.4	4.3
Air temperature (°C)	27	26	27	26
Concrete temperature (°C)	28	26	28	27
Concrete density (Kg/m ³)	2331	2332	2332	2332

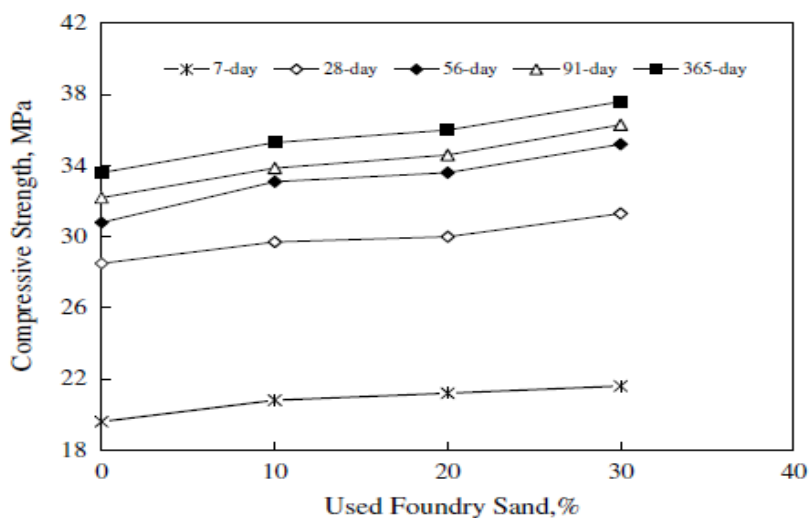


Fig. 2.1: Compressive strength in relation to used-foundry sand content and curing age, (Siddique et al. (2009))

The Fig. 2.1 shows that there was marginal increase in the compressive strength of concrete mixtures with the inclusion of UFS as partial replacement of regular sand. At 28-day, control mixture M-1 (0% UFS) achieved a compressive strength of 28.5 MPa, whereas mixtures M-2 (10% UFS), M-3 (20% UFS), M-4 (30% UFS) achieved a compressive strength of 29.7, 30.0, and 31.3 MPa, respectively; an increase of 4.2%, 5.2% and 9.8% in comparison with the strength of control mixture M-1 (0% UFS). With age (from 56 to 365 days), percentage increase in compressive strength for control mixture (without UFS) was between 8% and 18%, between 11.4% and 18.8% for mixture M-2, between 12% and 20% for mixture M-3, and between 12.4% and 20% for mixture M-4. Increase in the compressive strength of concrete mixes incorporating used-foundry sand indicated that foundry sand could be successfully used in making concrete as partial replacement of fine aggregate.

The increase in compressive strength with the inclusion of UFS could probably be due to the fact that UFS was finer than regular sand which resulted in the denser concrete matrix, and also due the silica content present in the UFS.

Naik et al. (2001), investigated the performance and leaching of controlled low strength materials (CLSM) incorporating fly ash and foundry sand. Two different CLSM (or flowable slurry) reference mixtures (equivalent to available production CLSM mixtures) were proportioned, using two sources of ASTM Class F fly ash. For each reference mixture, other mixtures were proportioned using two sources of foundry sand (molten metal-casting mold sand) as a replacement for fly ash in the range of 30–85%. Both clean (unused) and used foundry sands were incorporated in this investigation.

In this work, two reference flowable fly ash slurry mixtures were used. The first was proportioned with fly ash F1 for flow of 400 ± 25 mm (16 ± 1 in.). The second mixture was proportioned with fly ash F2 for flow of 280 ± 50 mm (11 ± 2 in.). Both mixtures were proportioned to obtain a flowable slurry, as defined by ACI Committee 229R-94 For each reference mixture, additional mixtures were proportioned with foundry sand as a partial replacement of fly ash. All mixtures were proportioned to have 28-day compressive strength in the range of 0.3–0.7 MPa (50–100 psi). A total of 18 different fly ash slurry mixtures were proportioned and produced Of these, two were the control mixtures without foundry sand, and the remaining sixteen had four different replacement levels of fly ash (30, 50, 70, and 85%) with two types of foundry sand (clean and used). The replacement of fly ash by the foundry sand was on a mass basis.

For each CLSM mixture, 150 mm diameter x 300 mm cylinders (6 in. diameter x 12 in.) were made for measurement of plastic properties as well as compressive strength of the flowable slurry mixtures. The mixture proportions are presented in Tables 2.3 and 2.4.

TABLE 2.3: Mixture Proportions and Fresh Slurry Properties for Fly Ash F1 Mixtures, (Naik et al. (2001))

Parameter	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9
Foundry sand ^a (%)	0	30(FS1)	50(FS1)	70(FS1)	85(FS1)	30(FS2)	50(FS2)	70(FS2)	85(FS 2)
Cement (Kg/m ³)	36	44	37	35	46	44	37	36	46
Fly ash (Kg/m ³)	1,044	899	737	482	244	899	737	490	248
Foundry sand (Kg/m ³)	0	398	756	1,149	1,274	405	757	1,104	1,434
Water (Kg/m ³)	540	450	406	363	363	450	405	368	369
W/ (C + FA)	0.50	0.48	0.52	0.70	1.25	0.48	0.52	0.70	1.25
Flow/ Spread (mm)	413	406	400	406	406	406	406	400	413
Air content (%)	1.2	1.2	0.6	0.6	0.7	1.2	0.8	0.7	0.7
Air temperature (°C)	13.9	11.1	14.4	16.7	14.4	13.9	14.4	14.4	14.4
Slurry temperature (°C)	16.1	16.1	15.6	16.7	16.1	17.2	19.4	17.8	17.2
Slurry density (Kg/m ³)	1,621	1,791	1,948	2,027	2,065	1,797	1,932	2,054	2,108

^aFS1 = clean foundry sand; FS2 = used foundry sand

TABLE 2.4: Mixture Proportions and Fresh Slurry Properties for Fly Ash F2 Mixtures, (Naik et al. (2001))

Parameter	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9
Foundry sand ^a (%)	0	30(FS1)	50(FS1)	70(FS1)	85(FS1)	30(FS2)	50(FS2)	70(FS2)	85(FS2)
Cement (Kg/m ³)	47	46	44	47	44	47	46	47	45
Fly ash (Kg/m ³)	834	795	634	451	242	812	666	478	249
Foundry sand (Kg/m ³)	0	356	633	1,105	1,461	549	710	1,166	1,503
Water (Kg/m ³)	685	561	507	297	322	361	467	351	311
W/ (C + FA)	0.78	0.67	0.75	0.60	1.12	0.42	0.66	0.67	1.05
Flow/ Spread (mm)	298	292	305	305	330	305	311	337	318
Air content (%)	0.8	1.2	0.4	0.5	0.4	1.3	0.5	0.3	0.3
Air temperature (°C)	14.4	34.4	32.8	14.4	16.1	15.5	14.4	16.1	16.1
Slurry temperature (°C)	17.2	18.9	18.3	18.9	19.6	17.2	17.8	19.4	20.6
Slurry density (Kg/m ³)	1,567	1,756	1,847	1,900	2,067	1,769	1,906	2,038	2,108

^aFS1 = clean foundry sand; FS2 = used foundry sand

The compressive strength increased with age (Figs. 2.2 and 2.3). The compressive strength for all slurry mixtures with and without foundry sand varied from 0.17 to 0.4 MPa (25 to 60 psi) at the 7 day age. The compressive strength values ranged from 0.27 to 0.55 MPa (40 to 80 psi) for the fly ash F1 mixtures and 0.3 to 0.6 MPa (45 to 90 psi) for the fly ash F2 mixtures at 28 days (Fig. 2.2). Generally, compressive strength increased with an increasing amount of foundry sand up to a certain limit, then decreased.

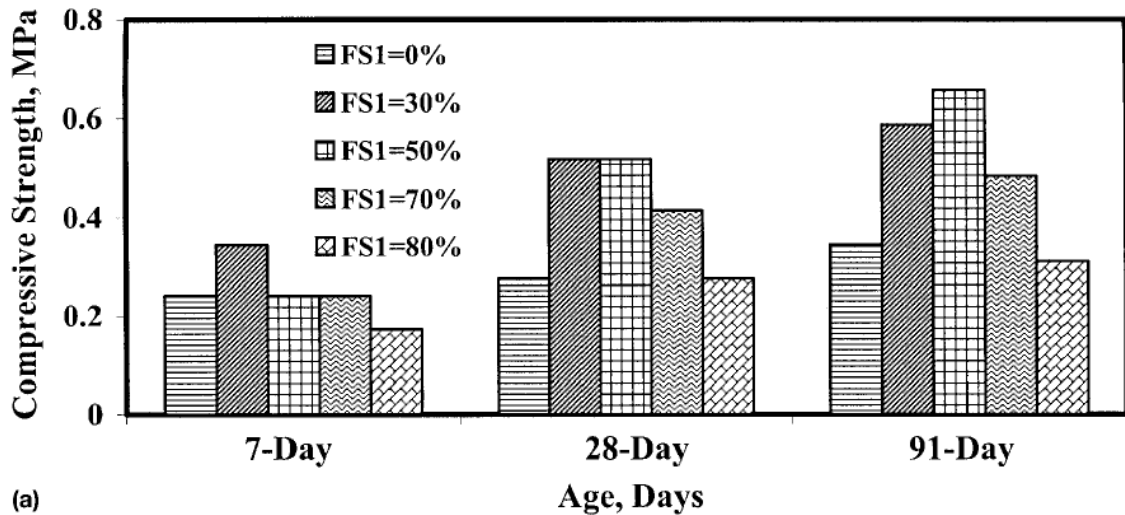


FIG. 2.2: Compressive Strength versus Age for Fly Ash F1 Mixtures: (a) Clean Foundry Sand (FS1) , (Naik et al. (2001))

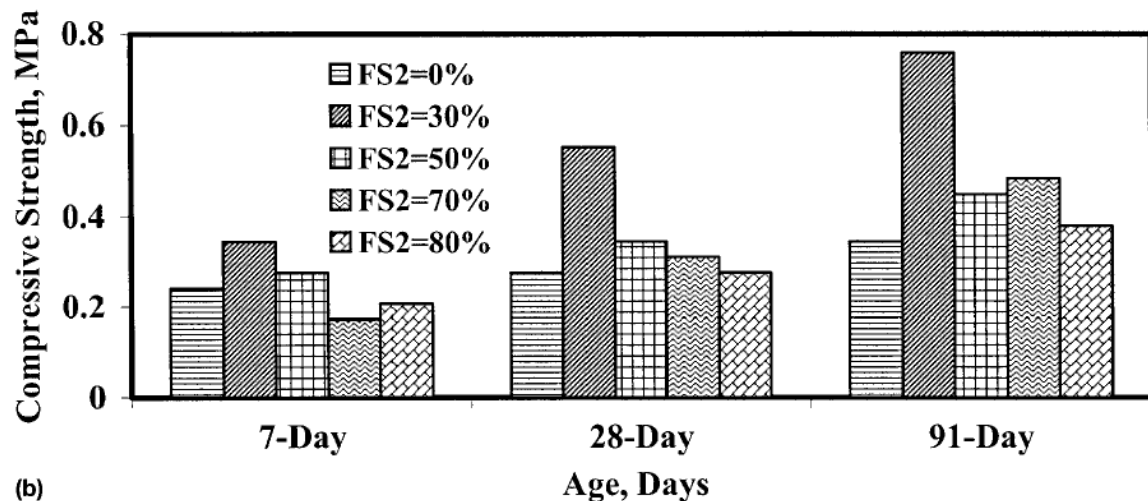


FIG. 2.2: Compressive Strength versus Age for Fly Ash F1 Mixtures: (b) Used Foundry Sand (FS2) , (Naik et al. (2001))

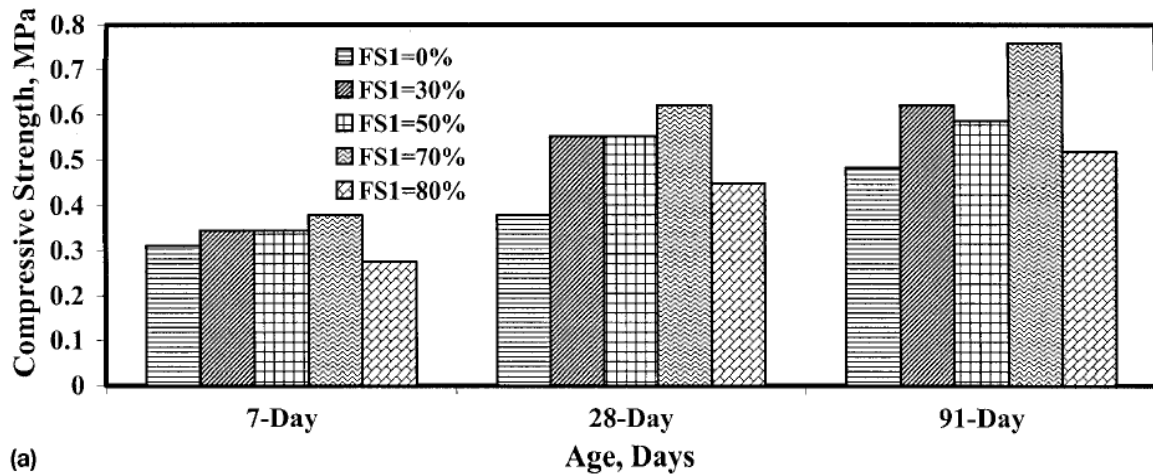


FIG. 2.3: Compressive Strength versus Age for Fly Ash F2 Mixtures: (a) Clean Foundry Sand (FS2) , (Naik et al. (2001))

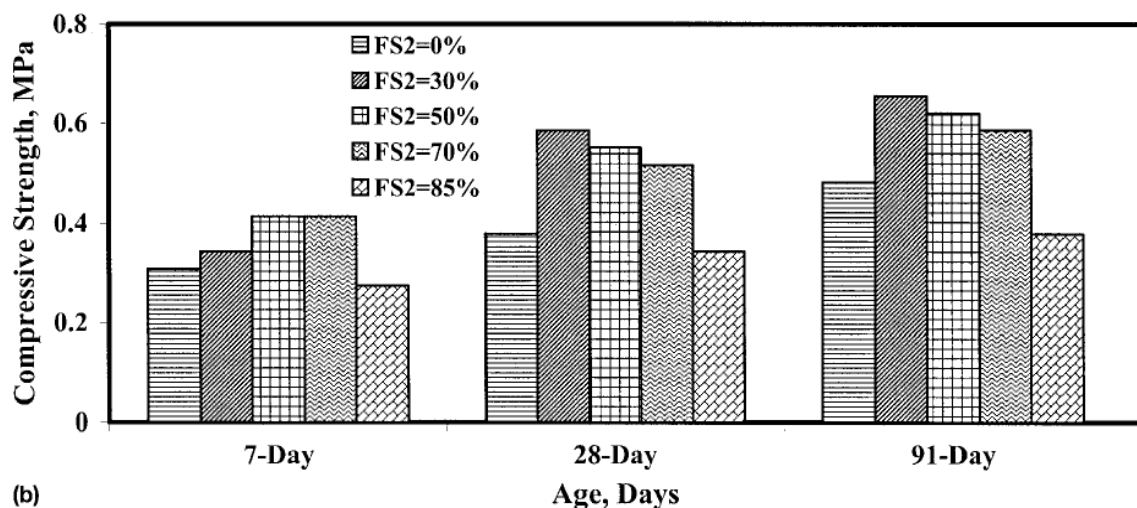


FIG. 2.3: Compressive Strength versus Age for Fly Ash F2 Mixtures: (b) Used Foundry Sand (FS2) , (Naik et al. (2001))

Guney et al. (2010), investigated the potential re-use of waste foundry sand in high-strength concrete production. The natural fine sand is replaced with waste foundry sand (0%, 5%, 10%, and 15%). ASTM C39 standard test method was used to test the compressive strength. The unconfined compression test results for the various amounts of waste foundry sand as partial replacement of fine aggregate at 28 and 56 days have been plotted in Fig.2.4. It can be seen, from Fig. 2.4, that the compressive strength increases with age for all the tested mixtures. It is also observed that the concrete with 10% waste foundry sand replacement

exhibits highest compressive strength at the age of 56 days. The compressive strength decreases with an increase in the amount of foundry sand. The concrete with 10% waste foundry sand shows almost the same strength as that in the control concrete mixture whereas all the other waste foundry-added mixtures exhibit lower values than that of the control.

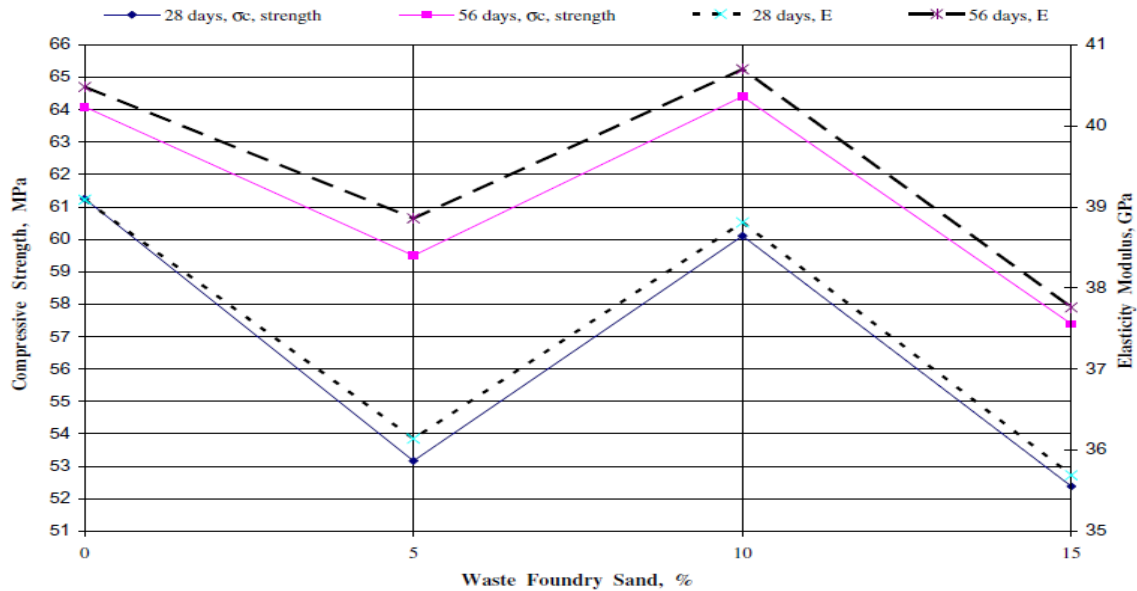


Fig. 2.4: Effect of waste foundry sand on compressive strength, (Guney et al. (2010))

Khatib and Ellis (2001), carried out a research on the compressive strength of concrete prepared with three types of foundry sand as a partial replacement for fine aggregate. Three types of sand were used in foundries: the white fine sand without the addition of clay and coal, the blended foundry sand (before casting), and the waste foundry sand. The standard fine sand was partially re-placed with these types of foundry sand (25%, 50%, 75%, and 100%).

The increase in the replacement level of standard sand with the foundry sand decreased the strength of the concrete linearly. The concrete with white sand replacement showed similar strength to those containing waste foundry sand. The high replacement of the blended foundry sand caused a reduction in strength as compared with concrete incorporating white sand or waste foundry sand.

Reddi et al. (1995), reported that compressive strength of stabilized foundry sands decreased with the increase in foundry sand content in the mixtures. Cement and fly ash mixtures were prepared by using 0, 25, 50, 75, and 100% levels of replacement of silica sand with spent

foundry sand. Water-to-cementitious binder ratio was 1.0 for mixtures made with Portland cement and 0.35 for mixtures containing fly ash. For each of the replacement levels, compressive strengths were obtained after 3, 7, 14, 28, and 56 days in order to evaluate the difference due to curing time. The clay bonded foundry sand reduced the strength of the stabilized mixes more than the chemically bonded foundry sands. A similar observation was made in context of fly ash stabilization. The drastic reduction in strength with an increase in clay-bonded foundry sand replacement was apparent in the cases of both fly ash and cement. Cement – stabilized mixes acquired their strength considerably slower than fly ash stabilized mixes. After 7 days of curing the cement-stabilized RBS reached only 30% of peak strength whereas its fly ash counterpart achieved 80% of its peak strength.

Tikalsky et al. (2000), compared the controlled low-strength materials mixtures containing clay-bonded and chemically bonded sand were compared in the plastic and hardened states to CLSM mixtures containing uniformly graded crushed limestone sand. Results showed that foundry sand can be successfully used in CLSM, and it provides similar or better properties to that of CLSM containing crushed limestone sand. The spent foundry sand assisted in keeping the strength from exceeding the desired upper limit of 0.70MPa. Clay-bonded sand retarded the setting time, and chemically bonded sands required a reduction in water to control bleeding. CLSM containing a combination of fly ash and chemically bonded sands was shown to have excellent characteristics for flowable backfill and excavatable base material.

2.1.2 Splitting Tensile strength

Siddique et al. (2007), determined the effect of spent foundry sand as partial replacement of fine aggregate on the splitting tensile strength of concrete. The proportions of fine aggregate replaced were 10, 20, and 30%. Tests were carried out at the age of 28 and 56 days. Test results of splitting tensile strength are shown in Fig. 2.5. The result concluded that the splitting tensile strength increased with the increase in foundry sand. At the age of 28 days, splitting tensile strength increased by 12, 14, and 20% when compared to ordinary mix without foundry sand, whereas increase was 6.0, 10, and 20% at the age of 56 days. Splitting tensile strength at 56 days was 20, 14, 14, and 20% higher than the 28 days strength.

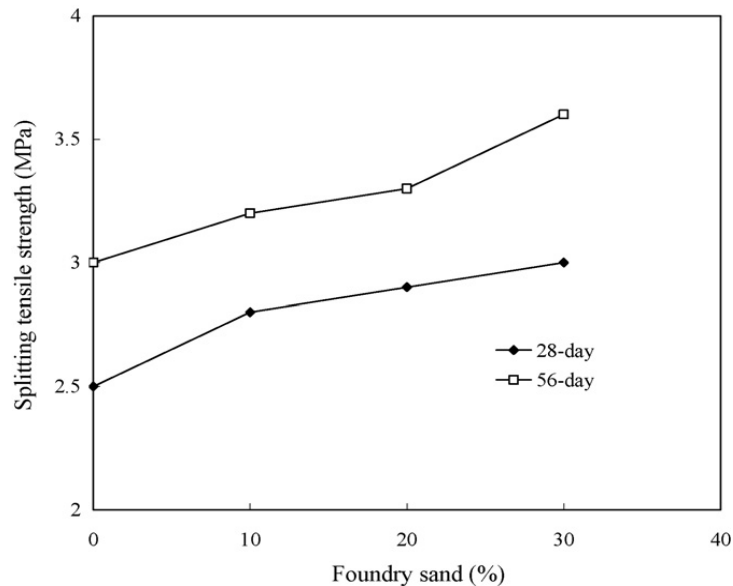


Fig. 2.5: Splitting tensile strength versus spent foundry sand, (Siddique et al., 2007)

Siddique et al. (2009), studied the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS). 150 x 300 mm cylinders were cast for this purpose. Fine aggregate was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. The splitting-tensile strength of concrete mixtures made with and without UFS was measured at the ages of 7, 28, 56, 91, and 365 days. The variation in the splitting tensile strength with UFS content was similar to that observed in the case of the compressive strength. Splitting tensile strength of concrete mixtures increased with the increase in UFS content. The fig. 2.6 shows the effect on concrete at different age. At 28-day, splitting-tensile strength of control mixture M-1 (0% UFS) was 2.75 MPa, whereas mixtures M-2 (10% UFS), M-3 (20% UFS), and M-4 (30% UFS) achieved strength of 2.85, 2.9, and 3.0 MPa, respectively. At 56-day, mixtures M-1 (0% UFS), M-2 (10% UFS), M-3 (20% UFS), and M-4 (30% UFS) achieved a strength of 2.93, 3.1, 3.17, and 3.24 MPa, respectively; an increase of 6.5%, 8.8%, 9.3% and 8% in comparison with 28-day strength.

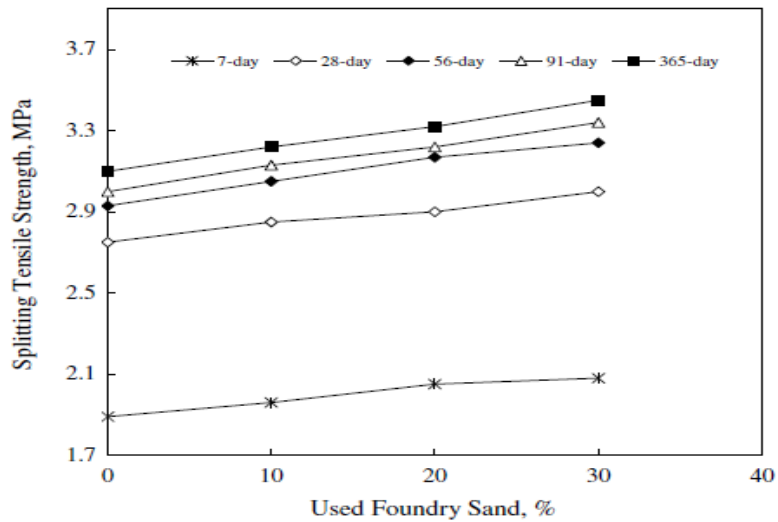


Fig. 2.6: Splitting-tensile strength in relation to used-foundry sand content and curing age, (Siddique et al. (2009))

Similar trend was also observed with 91 and 365-day splitting tensile strength results. With the increase in age from 56 to 365 days, percentage increase in splitting-tensile strength for control mixture (without UFS) was between 6.5% and 12.7%, 8.7% and 13% for mixture M-2, 9.3% and 14.5% for mixture M-3 and 8% and 15% for mixture M-4.

Guney et al. (2010), investigated the potential re-use of waste foundry sand in high-strength concrete production. The natural fine sand is replaced with waste foundry sand (0%, 5%, 0%, and 15%). Standard test method for splitting tensile strength of concrete specimens according to the ASTM C496 was conducted. The results show that the waste-foundry-sand-included mixtures develop substantial tensile strength that shows a close relationship with the content of such sand. The splitting tension test results of the specimens, with and without the foundry sand, are given in Fig. 2.7. The results of the splitting tension test can be considered as acceptable values when compared to that of the ACI 318 relation as in,

$$f_{sp} = 0.47 (f'_c)^{0.56} \text{ for } 5 \text{ Mpa} < f'_c < 120 \text{ Mpa}$$

where f_{sp} is the splitting tensile strength in MPa, and f'_c is the compressive strength in MPa.

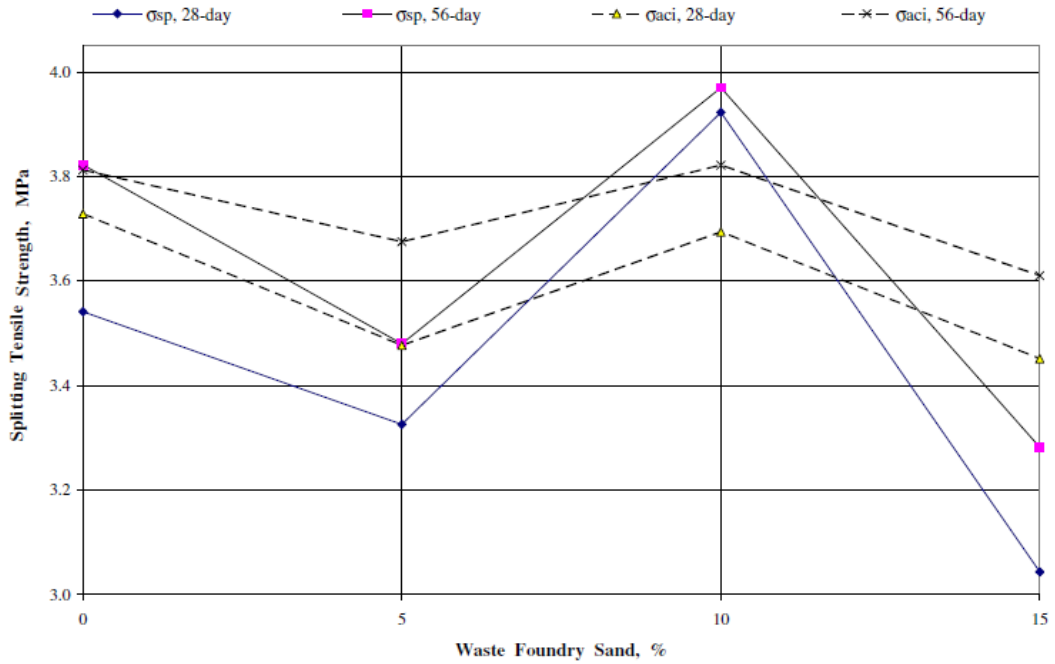


Fig. 2.7: Effect of waste foundry sand content on splitting tensile strength and ACI 318 calculations, (Guney et al. (2010))

The splitting tensile strength values of 5% and 15% waste-foundry-sand-replaced-specimens are lower than that of the control one; the specimens replaced with 10% waste foundry sand have slightly higher values than the control mix (without foundry sand).

Naik et al. (1994), investigated the performance of fresh and hardened concrete containing discarded foundry sands in place of fine aggregate. A total of five concrete mixes (two containing 25% and 35% partial replacement of regular sand with used foundry sand, two containing 25% and 35% partial replacement of regular sand with clean/new foundry sand, and one control mix) were investigated. 150 mm x 300 mm (6 in. x 12 in.) cylinders were cast in accordance with ASTM C 192 for measuring the splitting tensile strength of concrete at 3, 7 and 28 days. Table 2.5 shows the Concrete mix and test data for fresh concrete.

TABLE 2.5: Concrete Mix and Test Data for Fresh Concrete, (Naik et al. (1994))

(1)	Mix Number				
	20-F1 (2)	20-F2 (3)	20-F3 (4)	20-F4 (5)	20-F5 (6)
Specified design strength (Mpa)	38	38	38	38	38
Cement (Kg)	362	362	362	362	362
Water (Kg)	173	173	173	173	173
Sand (Kg)	859	644	558	644	558
Used foundry sand (Kg)	0	215	300	215	300
¾ in. Coarse aggregate (SSD, Kg)	1,074	1,074	1,074	1,074	1,074
Slump (mm)	152	32	29	133	120
Air content (%)	2.4	1.8	1.8	2.2	2.4
Air temperature (°C)	20	20	20	20	20
Concrete temperature (°C)	18	20	20	20	18
Fresh concrete density (Kg/m ³)	2,467	2,499	2,467	2,435	2,499
Hardened concrete bulk density (Kg/m ³)	2,450	2,435	1,450	2,450	2,450

Note: 1 MPa = 145.04 psi; 1 mm = 0.039 in.; 1°F = 1.8 °C + 32; 1 kg/m³ = 0.0624, lb/cu ft = 1.685 lb/cu yd

Splitting tensile strength tests were carried out on three cylinders for each mix, at each test age in accordance with ASTM C 496. The splitting tensile strengths for all mixes are shown in Table 2.6. The test data showed an increase in the tensile strength with age. Concrete mixtures containing 25% and 35% used foundry sand showed 20% to 40% reduction in tensile strength than that of control mix at the 28-day age. However, the ratio of tensile to compressive strength was relatively constant at 10-11% of compressive strength, except mix 20-F5, for which the ratio was 7.

**TABLE 2.6: Tensile Strength Data for Hardened Concrete (15 cm x 30 cm Cylinder) ,
(Naik et al. (1994))**

Test age (day s) (1)	Tensile strength									
	20-F1 38 MPA ^a 0% ^b		20-F2 38 MPA ^a 25% Falk ^b		20-F3 38 MPA ^a 35% Falk ^b		20-F4 38 MPA ^a 25% Badger ^b		20-F5 38 MPA ^a 35% Badger ^b	
	Actual (Mpa) (2)	Average (Mpa) (3)	Actual (Mpa) (4)	Average (Mpa) (5)	Actual (Mpa) (6)	Average (Mpa) (7)	Actual (Mpa) (8)	Average (Mpa) (9)	Actual (Mpa) (10)	Average (Mpa) (11)
3	2.6		1.8		2.0		2.6		2.0	
3	2.6	2.7	2.0	1.8	2.2	2.1	2.3	2.3	2.2	2.1
3	3.0		1.5		2.2		2.1		2.2	
7	3.2		2.9		2.4		3.6		2.4	
7	3.2	3.2	3.1	3.2	2.6	2.6	3.5	3.5	2.6	2.5
7	3.1		3.0		2.7		3.3		2.6	
28	4.7		3.9		2.9		4.4		3.1	
28	4.4	4.6	3.8	3.6	3.2	3.1	3.8	4.0	3.3	3.2
28	4.6		3.2		3.2		3.8		3.1	

Note: 1 MPa = 145.04 psi

^aSpecified design strength

^bPercentage of foundry sand replacing regular sand

Bakis et al. (2006), investigated the use of waste foundry sand (WFS) in asphalt concrete. Asphalt Concrete mixtures were prepared with 0, 4, 7, 10, 14, 17 and 20% replacement of fine aggregate with WFS. Tests were performed for indirect tensile strength as per AASTHO (1989). Results of the indirect tensile strength are shown in Fig. 2.8. The strength of the asphalt concrete mixtures showed a nearly linear decrease as the percentage of WFS was increased, yielding values from 1.39MPa with 0% WFS to 0.94MPa with 20% WFS.

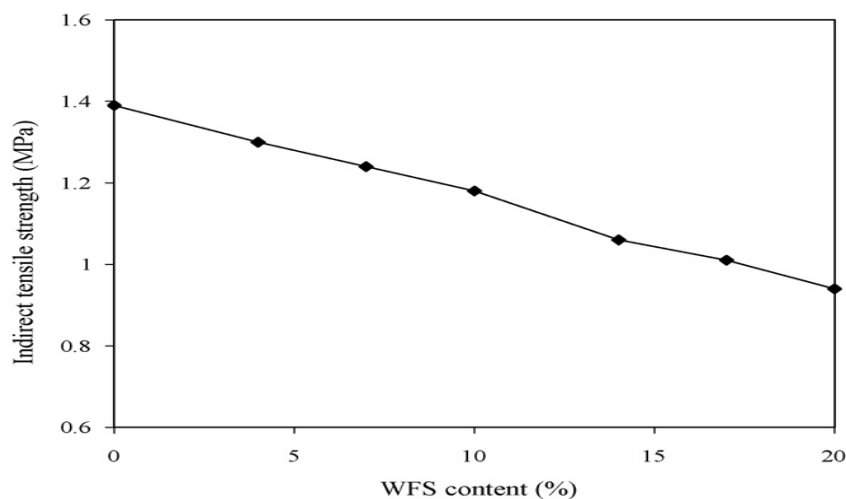


Fig. 2.8: Indirect tensile strength of WFS-asphalt cement mixtures according to AASTHO T283 (Bakis et al., 2006).

2.1.3 Flexural Strength

Siddique et al. (2009), studied the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS).

101.4 x 101.4 x 508 mm beams were cast for flexural strength. Fine aggregate was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. Flexural strength of concrete mixtures made with and without UFS was determined at the ages of 7, 28, 56, 91, and 365 days. The flexural strength test results of concrete mixtures are shown in Fig 2.9. At 28-day, splitting tensile strength of control mixture M-1 (0% UFS) was 3.41 MPa, whereas mixtures M-2 (10% UFS), M-3 (20% UFS), and M-4 (30% UFS) achieved strength of 4.0, 4.1, and 4.18 MPa, respectively. Flexural strength of concrete mixtures increased marginally with the increase in UFS content.

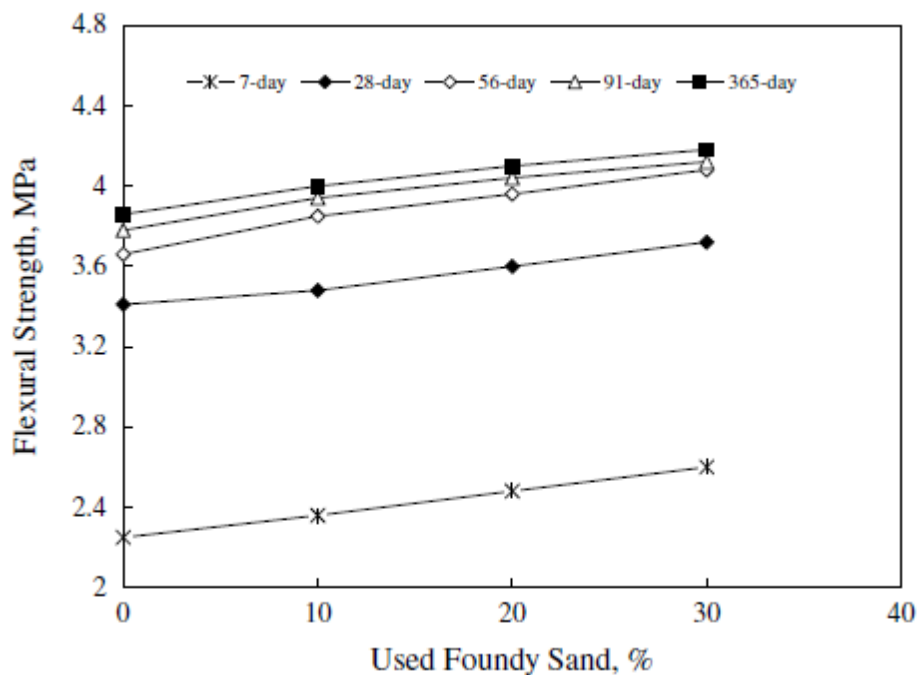


Fig. 2.9: Flexural strength in relation to used-foundry sand content and curing age, (Siddique et al. (2009))

2.1.4 Modulus of Elasticity

Siddique et al. (2007), determined the effect of spent foundry sand as partial replacement of fine aggregate on the modulus of elasticity of concrete. The proportions of fine aggregate replaced were 10, 20, and 30%. Tests were carried out at the age of 28 and 56 days. Test results of modulus of elasticity are shown in Figs. 2.10. The result concluded that the

modulus of elasticity of foundry sand fly ash concretes with 0, 10, 20, and 30% fine aggregate (sand) replacement was higher than the control mix at all ages. It is also evident that modulus of elasticity of all mixes continued to increase with age.

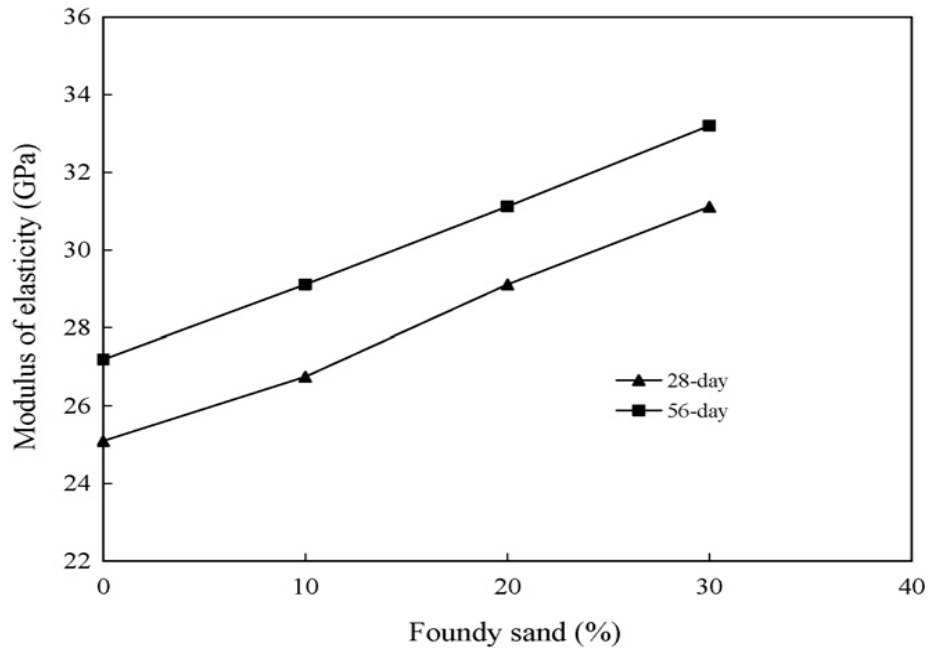


Fig. 2.10: Modulus of elasticity versus spent foundry sand, (Siddique et al., (2007))

Siddique et al. (2009), studied the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS). 150 x 300 mm cylinders were cast for this purpose. Fine aggregate was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. Modulus of elasticity of concrete mixtures was determined at 7, 28, 91, and 365 days, and results are shown in Fig. 2.11. Test results indicate that replacement of fine aggregate with UFS marginally enhanced the modulus of elasticity of concrete mixtures. At 28-day, control mixture M-1 (0% UFS) achieved a modulus of elasticity of 25.1 GPa, whereas mixtures M-2 (10% UFS), M-3 (20% UFS), and M-4 (30% UFS) achieved a modulus of elasticity of 26.75, 27.60, and 28.4 GPa, respectively. It is also evident that modulus of elasticity of all the mixtures continued to increase with age. Increase in modulus of elasticity varied between 5.2% and 12% depending upon UFS content and age of testing.

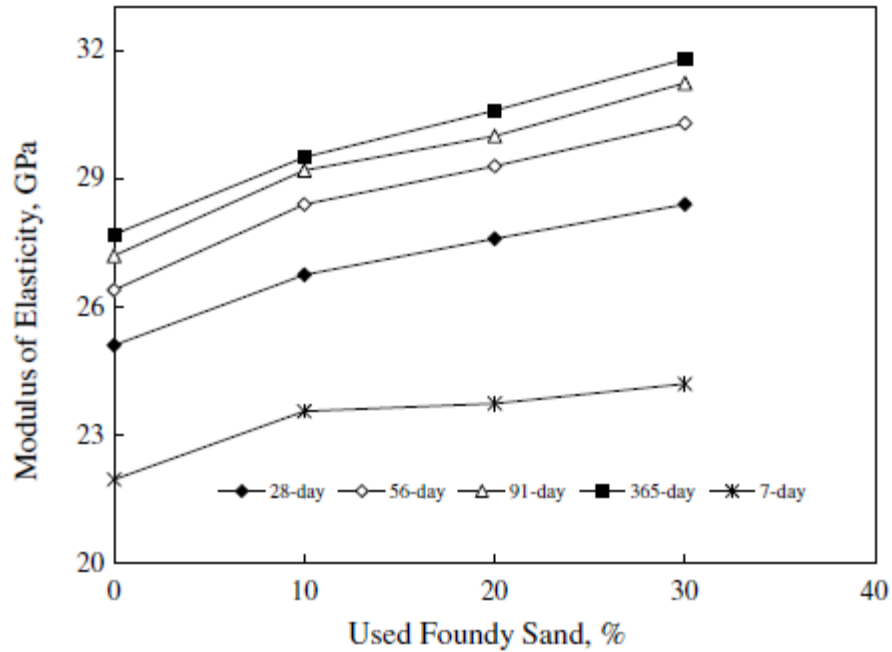


Fig. 2.11: Modulus of elasticity in relation to used-foundry sand content and curing age, (Siddique et al. (2009))

Guney et al. (2010), investigated the potential re-use of waste foundry sand in high-strength concrete production. The natural fine sand is replaced with waste foundry sand (0%, 5%, 0%, and 15%). The modulus of elasticity is also calculated according to the equation suggested by the ACI 318 at the age of 28 and 56 days, as follows:

$$E = 0.043 \times W^{3/2} \times \sigma^{1/2}$$

Where E is the modulus of elasticity in MPa, W is density in kg/m^3 , and σ is the unconfined compressive strength in MPa. The calculated moduli of elasticity have also been provided in Fig. 2.12. It is obvious from Eq. (1) that the static modulus of elasticity is a function of the compressive strength of the concrete. If the compressive strength of the concrete increases, the static modulus of elasticity will also increase, and vice versa.

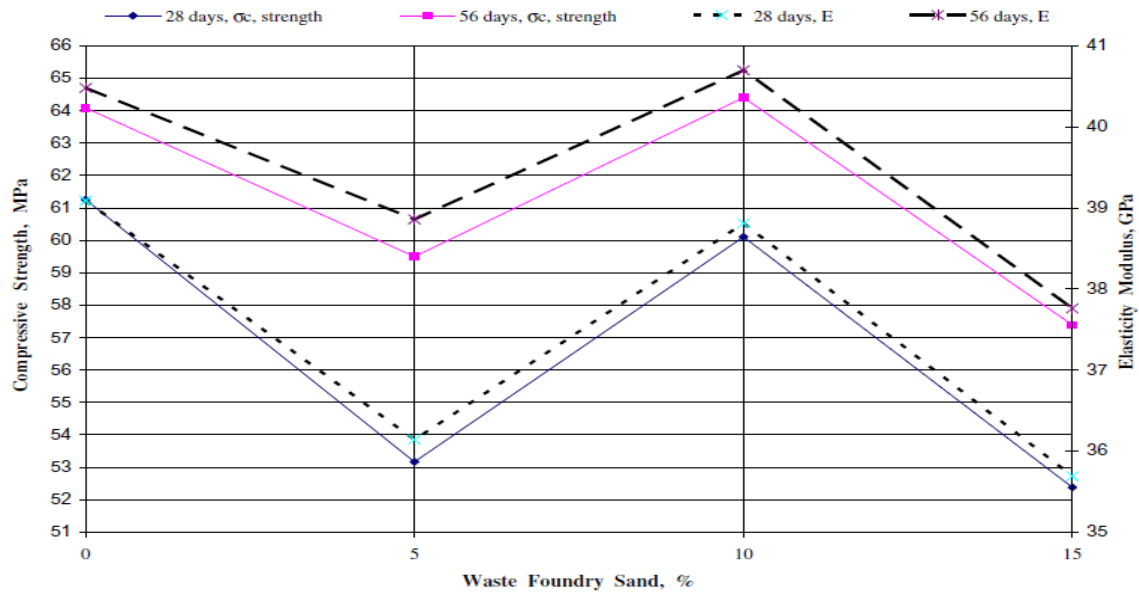


Fig. 2.12: Effect of waste foundry sand on compressive strength and modulus of elasticity, (Guney et al. (2010))

Naik et al. (1994), investigated the performance of fresh and hardened concrete containing discarded foundry sands in place of fine aggregate. A total of five concrete mixes (two containing 25% and 35% partial replacement of regular sand with used foundry sand, two containing 25% and 35% partial replacement of regular sand with clean/new foundry sand, and one control mix) were investigated. 150 mm x 300 mm (6 in. x 12 in.) cylinders were cast in accordance with ASTM C 192 for measuring the modulus of elasticity of concrete.

From the Table 2.7, the modulus of elasticity of the concrete containing 25% and 35% used foundry sand is lower than that of control mix at early ages. However at 28-day age the control mix and mix with 25% foundry sand shows approximately the same value of modulus of elasticity. However, the 28-day modulus of elasticity of concrete containing 25% and 35% of clean foundry sand is slightly greater than that of the control mix.

TABLE 2.7: Modulus of Elasticity Test Data, (Naik et al. (1994))

Test age (days) (1)	Modulus of Elasticity									
	20-F1		20-F2		20-F3		20-F4		20-F5	
	Actual (Mpa) (2)	Average (Mpa) (3)	Actual (Mpa) (4)	Average (Mpa) (5)	Actual (Mpa) (6)	Average (Mpa) (7)	Actual (Mpa) (8)	Average (Mpa) (9)	Actual (Mpa) (10)	Average (Mpa) (11)
3	22,000		20,000		17,900		22,700		24,100	
3	22,800	22,500	20,700	20,200	20,000	18,400	23,400	23,900	18,600	20,900
3	22,800		20,700		17,300		25,500		20,000	
7	25,500		28,400		22,000		26,900		26,200	
7	26,200	24,300	23,500	24,500	24,100	23,400	24,100	25,000	28,300	27,600
7	21,400		21,400		24,100		24,100		28,300	
28	31,700		31,700		33,100		30,400		33,100	
28	32,400	31,700	31,000	31,700	31,000	32,600	36,600	33,400	33,100	33,300
28	31,000		32,400		33,800		33,100		33,800	

2.1.6 Leachate analysis

Ham and Boyle (1981), evaluated the leaching characteristics of spent foundry sand and concluded that: (i) leaching potential was greatly influenced by the process temperature; (ii) constituents of the leachates depended upon the type of foundry sand, which reflected the differences in the binder material present in the waste material.

Fero et al. (1986), determined the concentration of organic compounds in ground water leached from an iron foundry landfill. Test samples derived from all monitoring wells showed all measured organics were below their respective detection limits.

Engroff et al. (1989), evaluated the leachate characteristics of foundry sands derived from nine common core binder systems using the toxicity characteristic leaching procedure (TCLP) test method. The test data showed the presence of a wide range of organic compounds, but their concentrations were low.

Ham et al. (1990), compared the leachate quality in foundry landfills with samples taken from above the zone of saturation. Their results indicated that leachates from the unsaturated zone had relatively low concentrations of contaminants with respect to drinking water standards for all contaminants except, iron, manganese, and fluoride. A leaching test conducted on auger waste samples was more accurate in predicting field leachate compositions than the leaching test on a raw composite waste.

Tikalsky et al. (1998), reported that the swelling potential and instability of bentonite-stabilized mixes render the leachable quality unpredictable. The data on total phenolics obtained from leachability experiments were normalized to account for difference in volumes of leachates collected for each stabilized mix. In the experiments, cement and fly ash mixtures were prepared using 0, 25, 50, 70, and 100% levels of silica sand by foundry sand. This normalization was important for unequal amounts of foundry sand used with each of four binders. To provide a basis for comparison among the four binders, treatment efficiencies were calculated representing the percentage of total phenolics immobilized due to stabilization process. The treatment efficiencies (TE) were used in the existing literature and involve normalizing the contaminants leached from stabilized product with respect to contaminant leached from untreated waste. The results showed that fly ash is more effective than cement in stabilizing the phenolics. Treatment efficiencies increased as the percentage replacement of foundry sands increased. In other words, the total phenolics leached from each stabilized gram of foundry sands decreased as higher proportions of clean sand were replaced by foundry sand. So the swelling potential and instability of bentonite-stabilized mixes render the leachate quality unpredictable.

2.1.6 Freeze & Thaw resistance

Guney et al. (2010), investigated the potential re-use of waste foundry sand in high-strength concrete production. The natural fine sand is replaced with waste foundry sand (0%, 5%, 0%, and 15%). After 120 days of curing, the specimens were frozen in a temperature chamber at -24 ± 1 °C for 24 h, and then thawed according to the ASTM C666. The durability of concrete in variable climatic conditions is an essential requirement for its application in the outdoor sections of buildings and structures. Tests for freeze–thaw resistance of concrete were performed as per the ASTM C 666 on 100 mm cubes subjected to cyclic freezing and thawing within the temperature range from -24 to $+24$ °C. The unconfined compressive strength was measured before and after 80 freezing and thawing cycles. The obtained results for the dynamic modulus of elasticity, E_d , are plotted in Fig. 2.13.

It can be observed that both the compressive strength and the dynamic modulus of elasticity decrease with the freezing and thawing cycles. The same trend has been noted in all the mixes; also, the concrete samples with 10% foundry sand mixture are slightly influenced by freezing and thawing cycles with respect to the other waste foundry sand replacement ratios.

On the other hand, the ACI 318-99 code sets a minimum specified compressive strength of 31.0 MPa for concrete exposed to freezing and thawing in a moist condition.

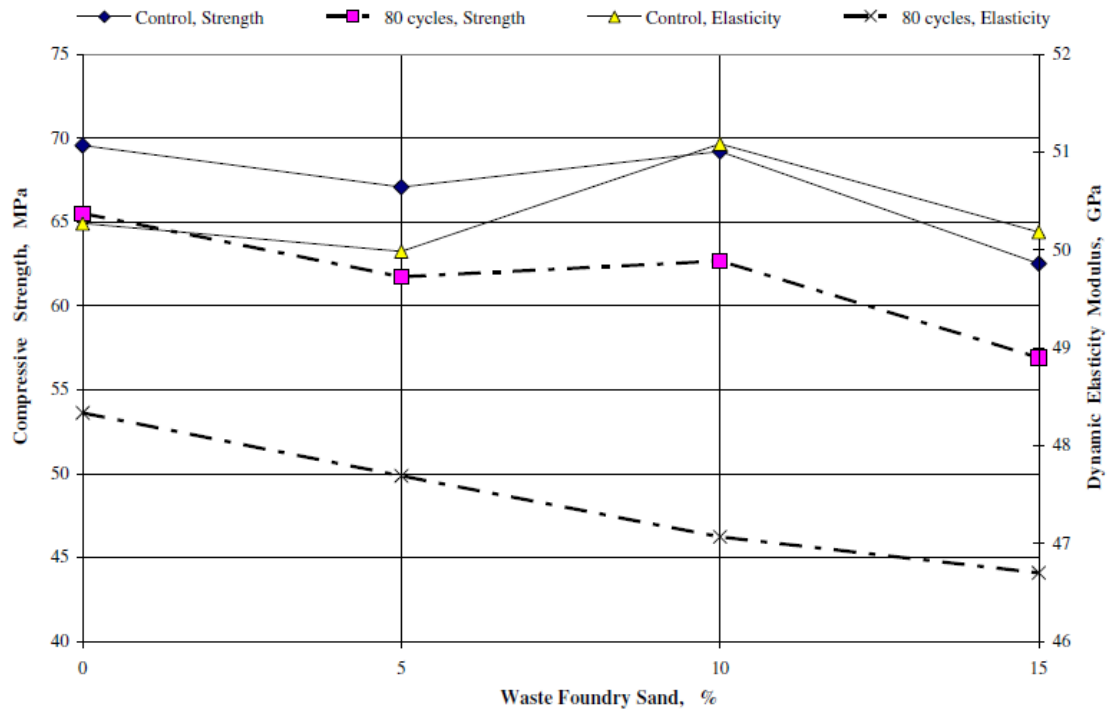


Fig. 2.13: Freezing–thawing influence on compressive strength and dynamic elasticity modulus, Guney et al. (2010)

CHAPTER 3

Experimental Programme

3.1 General

The aim of the experimental program is to compare the properties of cement mortar made with and without Foundry sand, used as fine aggregates. The basic tests carried out on materials used for casting mortar samples are discussed in this chapter. At the end, the various tests conducted on the specimens are discussed.

3.2 Material Used

3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The cement contains two basic ingredients namely argillaceous and calcareous. IS mark 43 grade cement (Brand- Ambuja cement) was used for all mixes. The cement used was fresh and without any lumps. Testing of cement was done as per IS: 8112-1989. The various tests results conducted on the cement are reported in Table 3.1.

Table 3.1: Properties of cement

S.No.	Characteristics	Values obtained	Standard values
1.	Normal consistency	34 %	-
2.	Initial setting time (minutes)	90 min.	Not less than 30
3.	Final setting time (minutes)	255 min.	Not greater than 600
4.	Fineness (%)	3.5 %	<10
5.	Specific gravity	3.125	

3.2.2 Fine aggregates

The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was first sieved through 4.75 mm

sieve to remove any particles greater than 4.75 mm and remove the dust. Properties of the fine aggregate used in the experimental work are tabulated in Table 3.2. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 3.3.

Table 3.2: Properties of fine aggregates

S.No.	Characteristics	Value
1.	Type	Uncrushed (natural)
2.	Specific gravity	2.57
3.	Total water absorption	1.02 %
4.	Fineness modulus	2.28

Table 3.3: Sieve analysis of Fine aggregates

Sieve size	Weight retained (g)	Weight retained (%)	Cumulative Weight (%)
4.75 mm	3	0.3	0.3
2.36 mm	19.5	1.95	2.25
1.18 mm	46.5	4.65	6.9
600 μ	67.5	6.75	13.65
300 μ	132	13.2	26.85
150 μ	520	52	78.85
Pan	211.5	21.15	100
		$\Sigma F = 228.77$	

Fineness modulus of Fine aggregates = $\Sigma F/100 = 228.77/100 = 2.28$

3.2.3 Foundry sand

Investigations were made on foundry sand procured from Deluxe Foundry, Mandi Gobindgarh, Punjab. The chemical and physical properties of the foundry sand used in this investigation are listed in Table 3.4 and Table 3.5 respectively. Table 3.6 shows the sieve analysis for various replacement levels of sand with foundry sand.

Table 3.4: Physical Properties of Foundry sand

Property	Results	Test methods
Specific Gravity	2.47	ASTM D854
Bulk Relative Density, kg/m ³	2589	ASTMC48/AASTHO T84
Absorption, %	0.45	ASTM C128
Moisture content, %	0.1-10.1	ASTM D2216
Clay Lumps and Friable Particles	1- 44	ASTM C142/AASTHO T112
Coefficient of Permeability (cm/sec)	10 ⁻³ -10 ⁻⁶	AASTHO T215/ASTM D2434
Plastic Limit/Plastic Index	Nonplastic	AASTHO T90/ASTM D4318

Table 3.5: Chemical composition of Foundry sand

Constituent	Value
SiO ₂	87.91
Al ₂ O ₃	4.70
Fe ₂ O ₃	0.94
CaO	0.14
MgO	0.30
SO ₃	0.09
Na ₂ O	0.19
K ₂ O	0.25
TiO ₂	0.15
P ₂ O ₅	0.00
Mn ₂ O ₃	0.02
SrO	0.03
LOI	5.15
TOTAL	99.87

Table 3.6: Sieve analysis of Foundry sand

Sieve size	Weight retained (g)	% Weight retained	Cumulative % Weight
4.75 mm	10	1	1
2.36 mm	5	0.5	1.5
1.18 mm	6	0.6	2.1
600 μ	5	0.5	2.6
300 μ	40.5	4.05	6.65
150 μ	712.5	71.25	77.9
Pan	221	22.1	100
		$\Sigma F = 191.75$	

Fineness modulus of Foundry sand = $\Sigma F/100 = 191.75/100 = 1.91$

3.2.4 Water

Generally, water that is suitable for drinking is satisfactory for use. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in the mix, unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent discharge of harmful wastes into the stream. In the present experimental programme, potable tap water is used for casting.

3.3 Mix Designation

Mix has been designed based on Indian Standard Recommended Guidelines IS: 10262-1982. The proportion for the mortar, as determined is 1:3 with a water cement ratio of 0.54. The mix designation and quantities of various materials for each designed mortar mix have been tabulated in Table 3.7 for cubes.

Table 3.7: Mix Designation

Mix	% of Foundry sand	Cement (Kg)	Sand (Kg)	Foundry sand (Kg)	Water (Lit.)
M1	0	3	9	-	1.380
M2	10	3	8.1	0.9	1.380
M3	20	3	7.2	1.8	1.380
M4	30	3	6.3	2.7	1.380
M5	40	3	5.4	3.6	1.380
M6	60	3	3.6	5.4	1.380
M7	100	3	-	9	1.380

3.4 Batching, Mixing & Casting of Specimens

A careful procedure was adopted in the batching, mixing and casting operations. The fine aggregates were weighed first with an accuracy of 0.5 grams. The mixture was prepared by hand mixing on a watertight platform. PPC having 43 grades was used in casting. Three proportions of fine aggregates are replaced with foundry sand and thoroughly mixed. Then water was added carefully so that no water was lost during mixing. Fifteen clean and oiled moulds for each category were then placed on the vibrating table respectively for the cubical samples for compression strength testing. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould.

Cubical mould of size 70.9 mm x 70.9 mm were used to prepare the specimens. Care was taken during casting and vibrator was used for proper compaction. All the specimens were prepared in accordance with Indian Standard Specifications IS: 516-1959. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage out of slurry.

The specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were demoulded with care so that no edges were broken and were placed in the curing tank at the ambient temperature for curing. The ambient temperature for curing was $27 \pm 20^{\circ}\text{C}$.

3.5 TESTS CONDUCTED

3.5.1 Compressive strength

Cubical specimens of size 70.9 mm were cast for conducting compressive strength test for each mix. The compressive strength test was carried out as per IS: 516-1979. In this test six cubes from each mix were tested. The test was carried at the end of 28 & 90 days of curing. The compressive strength of any mix was taken as the average of strength of three cubes.



Plate 3.1: Compression Testing machine

3.5.2 Sulphate resistant test

In this four test specimens are immersed in the water containing $MgSO_4$ solution for 28 & 90 days and checked for if there is any change in its weight, colour, appearance & compressive strength. The sulphate solution is added at the rate of 5 mg/ 1000 ml. Magnesium sulphate leads to a complete reaction until all the magnesium is used up.

3.5.3 Porosity

The samples were oven dried for 24 hours at $105^{\circ}C$ and then cooled for the next 24 hours and weighed. Then the samples were kept under vacuum for 24 hours and allowed to equilibrate for the next 24 hours. The samples were then weighed in air and water. The difference in the weight of the sample gives the porosity.

$$P = \frac{B - A}{B - C} \times 100$$

where; P is porosity (%); A is oven-dry weight; B is saturated surface dry weight; C is saturated submerged weight.

3.5.4 XRD analysis

It is a powerful method by which X-Rays of a known wavelength are passed through a sample to be identified in order to identify the crystal structure. The wave nature of the X-Rays means that they are diffracted by the lattice of the crystal to give a unique pattern of peaks of 'reflections' at differing angles and of different intensity. The X-Ray detector moves around the sample and measures the intensity of these peaks and the position of these peaks [diffraction angle 2θ]. The X-rays used are of the Copper $k\alpha$ wavelength. The sampling is done in the powdered form is taken from the each mix. About 1 mg of sample is poured on the XRD slide, the excess powdered is removed off from the slide. The sample is now ready to be inserted into the X-Ray machine.

XRD measurements were done using Panalytical X'Pert Pro system with monochromatic Cu $K\alpha$ radiation having wavelength ($\lambda = 1.54 \text{ \AA}$). The data were collected for all samples at room temperature in the range of $5^\circ \leq 2\theta \leq 100^\circ$ at the scan speed of $5^\circ/\text{min}$.



Plate 3.2: XRD Machine

Table 3.8: XRD Sample details

S.No.	Sample Lable	Foundry sand (%)
1.	Sample I	0
2.	Sample II	10
3.	Sample III	30
4.	Sample IV	40
5.	Sample V	100

CHAPTER 4

Results & Discussions

4.1 General

Various properties of cement mortar incorporating foundry sand at various replacement levels with fine aggregate were studied. Tests were conducted for compressive strength, porosity, sulphate attack & XRD of mortar mixes.

4.2 Compressive strength

In this test, the values of compressive strength for different replacement levels of foundry sand contents (0%, 10%, 20%, 30%, 40%, 60% & 100%) at the end of different curing periods (28 days, 91 days) are given in Table 4.1. These values are plotted in Figs. 4.1 & 4.2, which show the variation of compressive strength with fine aggregate replacements at different curing ages respectively.

Table 4.1: Increase in the strength of mortar after 90 days w.r.t 28 days

Foundry sand (%)	Compressive strength (MPa)		Increase in the strength (%)
	28 days	90 days	
0	33.58	36.64	9.11
10	28.67	28.8	0.45
20	24.97	25.05	0.32
30	20.71	22.36	7.97
40	21.13	21.52	1.84
60	17.07	17.78	4.16
100	8.23	14.18	72.3

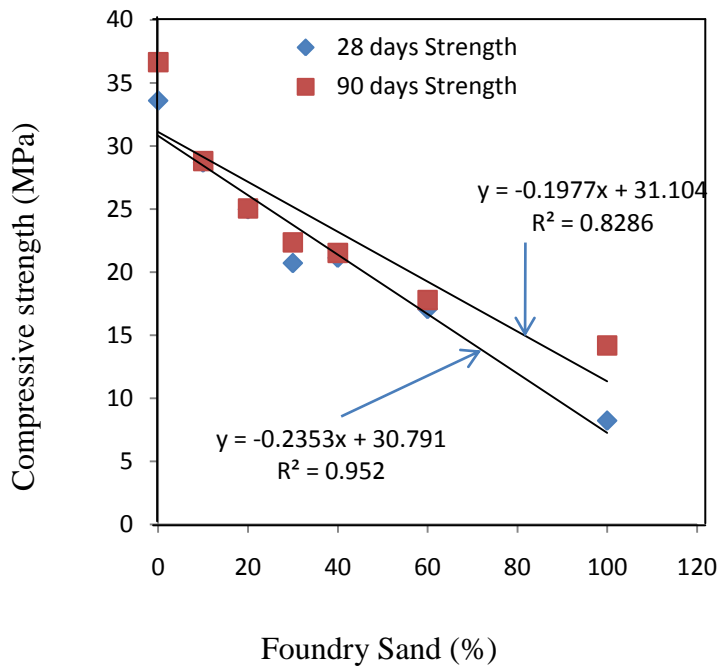


Fig 4.1: Relationship between Compressive strength & Foundry sand

It can be seen from the Fig.4.2 that the addition of foundry sand reduce the early strength of mortar, but the strength at the age of 90 days was found to be slightly increasing with respect to the 28 day.

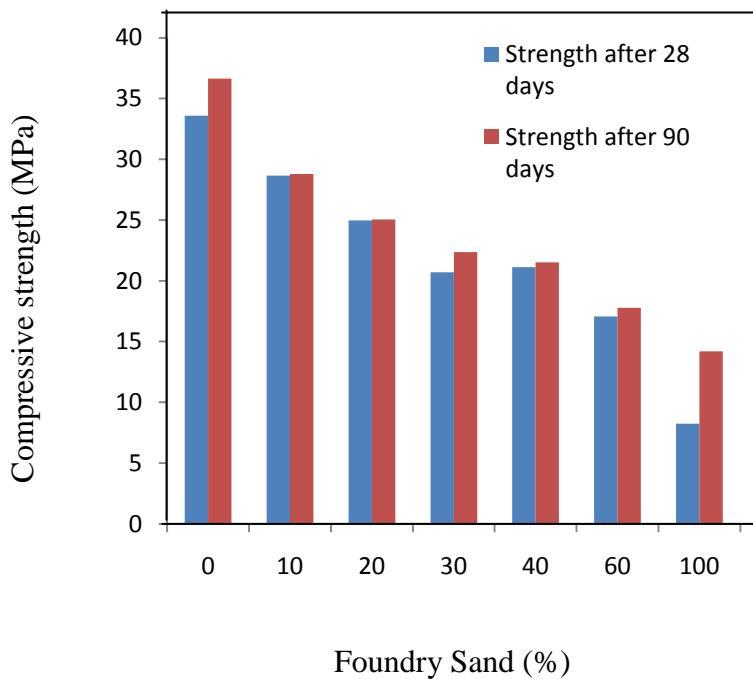


Fig. 4.2: Compressive strength at different ages

It can be seen from the Figs. that with the increase in the foundry sand the compressive strength decreases. At 28 days, the compressive strength reduction was 14.62%, 25.64%, 38.32%, 37.07%, 49.17% & 75.15% whereas at 90 days the reduction was 21.4%, 31.63%, 42.45%, 41.26%, 51.47% & 61.3% for the mix of 0, 10, 20, 30, 40, 60 & 100% replacement levels.

But with the increase in age an increase in the strength has been recorded at 90 days. It can be seen from the Table 4.1 that the increase was more at 30% replacement at 90 days.

4.3 Sulphate attack

It was found that due to sulphate attack the compressive strength of mortar incorporating foundry sand (using 10%, 20%, 30%, 40%, 60% & 100% replacement levels with fine aggregate) depended on the percentage of foundry sand used. The variation of compressive strength due to Sulphate attack was shown in Table 4.2.

Table 4.2: Compressive strength after Sulphate attack

Foundry sand (%)	Compressive strength (MPa)		Strength variation after sulphate attack (%)
	28 days	90 days	
0	30.28	32.64	7.79
10	24.38	24.89	3.48
20	21.58	22.10	2.41
30	19.23	19.68	2.34
40	16.7	18.76	12.35
60	13.14	15.42	17.35
100	6.76	10.98	62.43

Fig. 4.3 shows that compressive strength decreases with the increase in percentage of foundry sand at both ages. At 28 days, the compressive strength reduction was 19.48%, 28.73%, 36.49%, 44.84%, 56.6% & 77.6% whereas at 90 days the reduction was 23.74%, 12.4%, 22%, 25.64%, 38.8% & 56.5% for the mix of 0, 10, 20, 30, 40, 60 & 100% replacement levels.

As in the case of sulphate attack for the compressive strength, it can be seen from the Figs. 4.3 & 4.4 that the strength increases at 90 days as compared to 28 days.

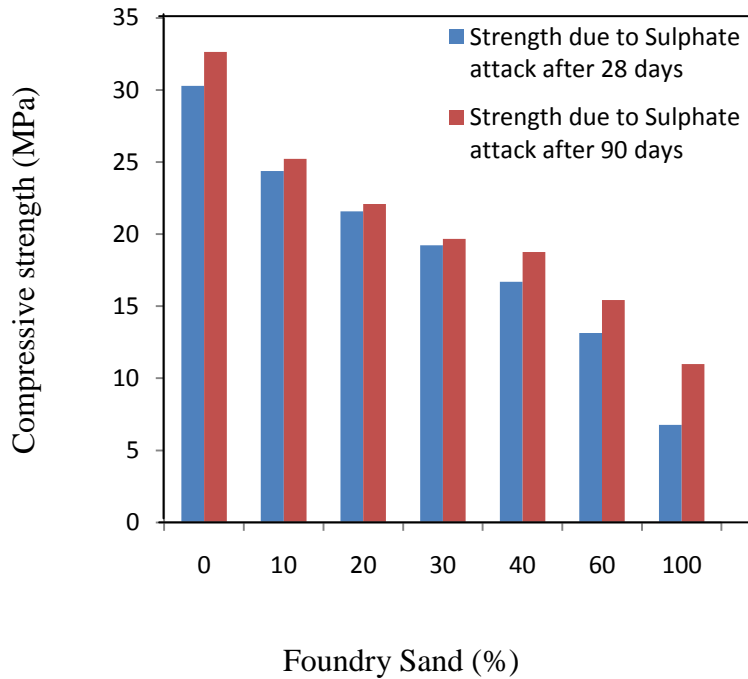


Fig. 4.3: Compressive strength due to sulphate attack at different ages

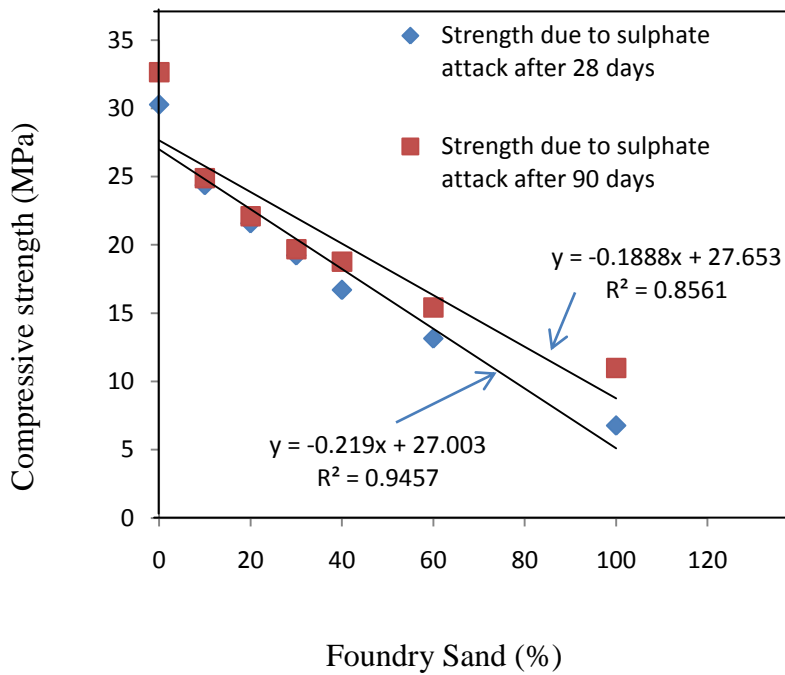


Fig 4.4: Relationship between Compressive strength & Foundry sand

The table 4.3 shows the mass loss of the samples after 28 & 90 days. It can be seen that the weight reduction was more at 30%, 40%, 60% & 100% replacement level of foundry sand at both 28 & 90 days.

Table 4.3: Mass loss due to sulphate attack

Foundry sand (%)	Weight reduction (%)	
	28 days	90 days
0	0.84	0.99
10	0.52	0.81
20	0.38	0.38
30	1.15	0.90
40	1.37	1.27
60	0.96	0.81
100	1.96	2.41

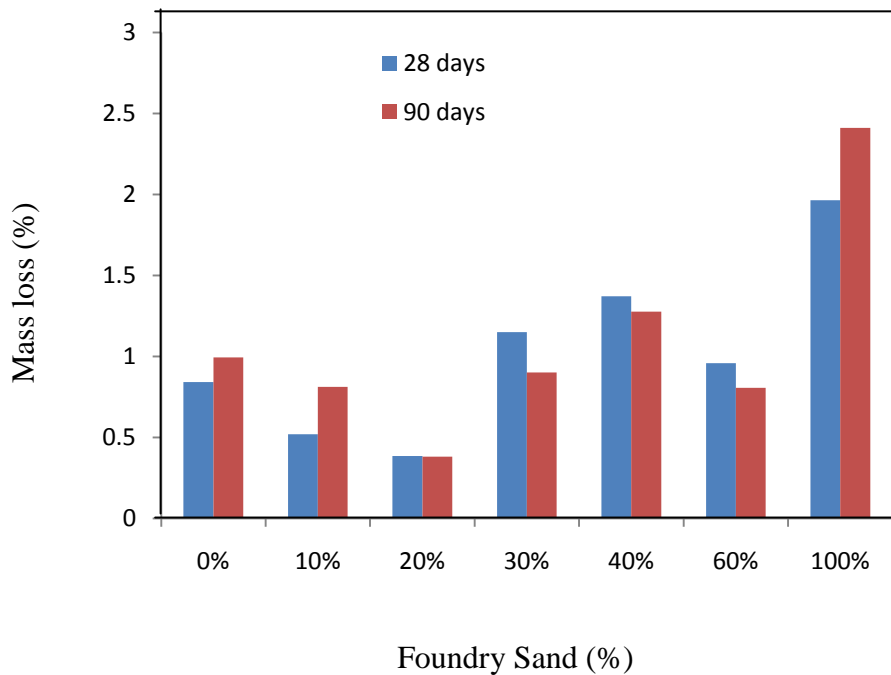


Fig 4.5: Mass loss due to sulphate attack

The Fig. 4.5 shows that the mass loss starts at a slow rate upto 20% replacement but after 20% the rate of loss increases slightly at the faster rate.

4.4 Porosity

The figure demonstrates the change in porosity of mortar at 28 & 90 days. The results indicate that the incorporation of foundry sand had a remarkable influence on porosity at all ages. At 28 & 90 days, it can be seen from the Fig. 4.6 that the porosity decreases with the increase of foundry sand. The inclusion of foundry sand resulted in a reduction in porosity for all mixes with respect to the controlled mix.

However, the reduction in the porosity of mortar was greater when 10%, 20%, 30% & 40% foundry sand was incorporated and this reduction was exhibited at all ages.

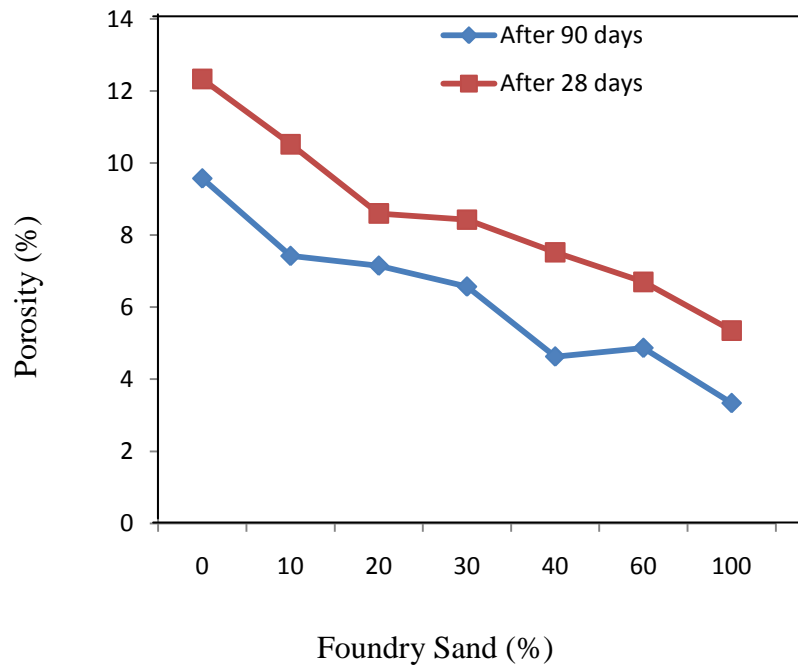


Fig. 4.6: Effect of FS on porosity of mortar

Table 4.4: Porosity of mortar mixes with FS

Foundry sand (%)	Porosity (%)		Reduction in the Porosity after 90 days (%)
	28 days	90 days	
0	12.33	9.57	22.38
10	10.52	7.42	29.47
20	8.6	7.15	16.86
30	8.43	6.57	22.06
40	7.52	4.63	38.43
60	6.7	4.87	27.31
100	5.35	3.34	37.57

The above Table 4.4 shows the % decrease in the porosity with the increase in age. It can be seen that the decrease up to 30% is 22.06%, whereas for 100% replacement comes out 37.57% after 90 days.

4.5 XRD analysis

By XRD (X- ray diffraction) Analysis we can know what type of chemical composition present in the mortar.

XRD technique was used to determine the state of chemical combination of the constituent components involved and phase present in the system. The powders of samples I, II, III, IV and V were characterized by X-ray diffraction analysis and the peaks were marked on the basis of ICDD data base.

The XRD pattern indicates that in the sample I the phases of Ca(OH)_2 , SiO_2 , Al_2SiO_5 and a mixed phase $\text{CaO.SiO}_2.\text{H}_2\text{O}$ were present. The all phases were indexed with their reference codes 01-084-1265, 01-089-1961, 01-072-1447 and 00-009-0210 respectively.

Table 4.5 (a): Chemical compounds found at 0% FS

Chemical compound	Visible	Reference code	Score
Calcium Silicate Hydrate	Yes	00-009-0210	1
Quartz low, syn	Yes	01-089-1961	66
dialuminium silicon oxide	Yes	01-072-1447	7
Calcium Hydroxide	Yes	01-084-1265	21

Table 4.5 (b): Chemical compounds found at 10% FS

Chemical compound	Visible	Reference code	Score
Calcium Silicate Hydrate	Yes	00-009-0210	1
Quartz low, syn	Yes	01-089-1961	78
Calcium Hydroxide	Yes	01-084-1265	16

Table 4.5 (c): Chemical compounds found at 30% FS

Chemical compound	Visible	Reference code	Score
Calcium Silicate Hydrate	Yes	00-009-0210	2
Quartz low, syn	Yes	01-089-1961	71
dialuminium silicate oxide, kyanite HP	Yes	01-072-1447	9
Portlandite, syn	Yes	01-084-1265	5

Table 4.5 (d): Chemical compounds found at 40% FS

Chemical compound	Visible	Reference code	Score
Calcium Silicate Hydrate	Yes	00-009-0210	1
Quartz, syn	Yes	01-089-1961	66
Portlandite, syn	Yes	01-084-1265	25

Table 4.5 (e): Chemical compounds found at 100% FS

Chemical compound	Visible	Reference code	Score
Calcium Silicate Hydrate	Yes	00-009-0210	2
Quartz	Yes	01-089-1961	70
Portlandite, syn	Yes	01-084-1265	22

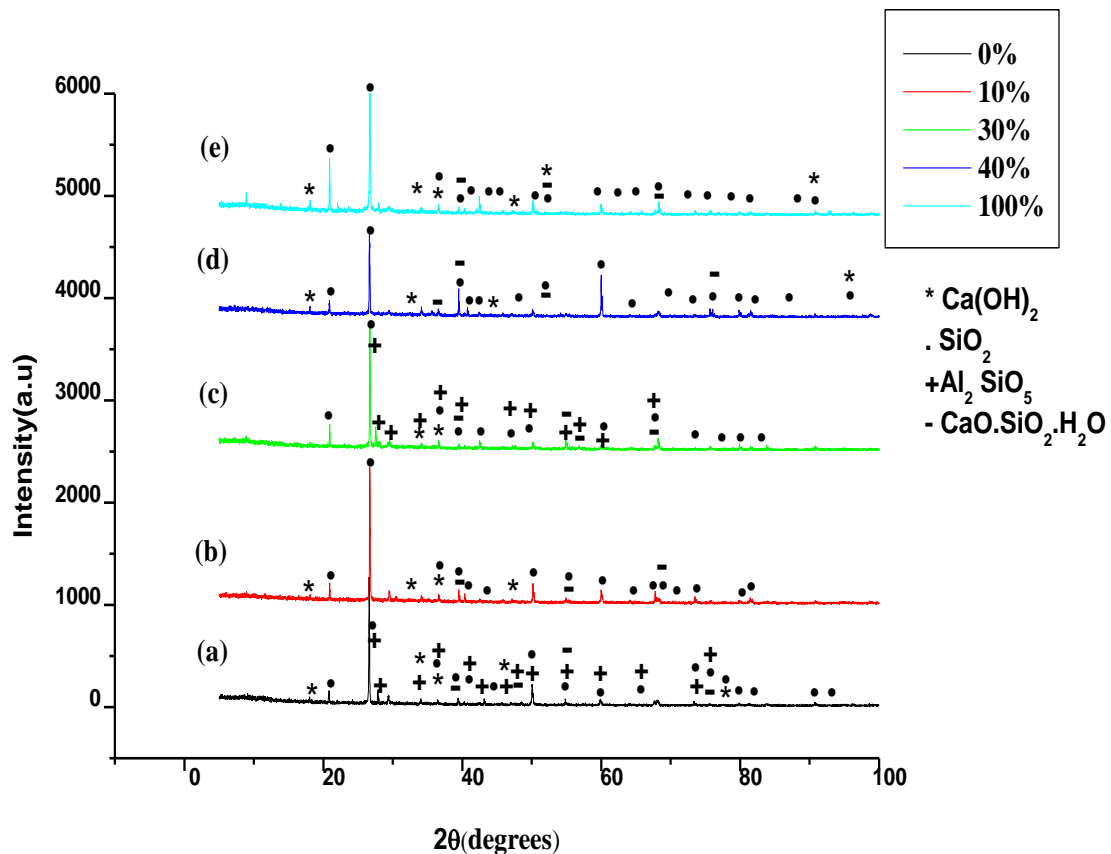


Fig. 4.7: X-ray diffraction patterns of (a) 0% foundry sand (b) 10% foundry sand (c) 30% foundry sand (d) 40% foundry sand (e) 100% foundry sand

The X-ray diffraction patterns of samples I, II, III, IV and V with different compositions are given above in the figure 4.7. Apart from this the phases Ca(OH)_2 , SiO_2 , and a mixed phase $\text{CaO.SiO}_2.\text{H}_2\text{O}$ were present in all compositions.

It was observed that in all the compositions as we are increasing the percent of foundry sand the phase Al_2SiO_5 is going to diminish in all the compositions. The detail of all samples taken from the table 3.8. As we can see from the Figure 4.7 that in the sample I the phase (Al_2SiO_5) is going to change in the phase SiO_2 in the sample II at an angle nearly 42° . We can also observed that at higher angle the SiO_2 phase is decreasing in the sample II as compared to sample I. Moreover, in the sample III at an angle nearly 29° the extra phase (Al_2SiO_5) is present. Here we also observed that from figure 4.7 nearly at an angle 98° the extra peak of $\text{Ca}(\text{OH})_2$ and SiO_2 phases were going to formed in the sample IV and sample V. As we are going to increase the concentration of foundry sand in all compositions the densification is going to increase and the porosity is going to decrease which is given in the Table 4.4.

Here we mentioned earlier the phase Al_2SiO_5 is going to diminish in all the samples as we are increasing the concentrations of foundry in all the compositions. Because of increasing foundry sand in all the compositions the sulphate attack is going to increase and the phase Al_2SiO_5 going to decrease.

Moreover, the compressive strength is also going to decrease as mentioned in the Table 4.1. The XRD analysis results on the samples for 28 days from the Fig 4.7 shows that at angles 39.5° , 55° & 68.5° in all the samples the peak intensity of C-S-H (Calcium- Silicate-Hydrate) gel formation is reducing, which shows that cement doesn't react properly with foundry sand & hence due to which the gel formation is reducing. Silica in the foundry sand wasn't consumed to form calcium silicate hydrates, which in turn hardened the specimen. As the gel formation isn't good the compressive strength also decreases.

CHAPTER- 5

CONCLUSIONS & SCOPE OF FURTHER STUDY

5.1 Conclusions

The following conclusions are drawn from this study:

1. Compressive strength of mortar decreased with the increase in sand replacement with different replacement levels of foundry sand. However, at each replacement level, an increase in strength was observed with the increase in age.

2. The compressive strength decreased upto 75.5% when compared to ordinary mix without foundry sand at 28-days & 61.3% at 90 days.

3. In the Sulphate attack test, also the Compressive strength decreases with sand replacement.

4. The compressive strength in Sulphate solution decreased by upto 77.6% when compared to ordinary mix without foundry sand at 28-days & 56.5% at 90 days. Attack by any Magnesium salt is therefore the most damaging to concrete.

5. An increase in the replacement level of the sand with waste foundry sand decreased the compressive strength. Using waste foundry sand with a ratio less than 10% can be inadequate and using more than 20% will be an excessive amount as far as the strength parameters are concerned.

6. The Porosity of the mortar decreases with increase in sand replacement with different replacement levels of foundry sand.

7. At 28-days, the porosity decreased upto 5.35% respectively whereas at 90 days the reduction was 3.34% respectively.

8. The mortar with waste foundry sand higher than 10% exhibited reductions in water absorption and void ratios. The reduction in these ratios may be due to the void-padding effect of clay-type materials in the waste foundry sand.

9. From the XRD test it was observed that with the increase in foundry sand the porosity decrease due to the densification.

10. As it can be seen from the XRD peaks that at angles 39.5° , 55° & 68.5° in all the samples the peak intensity of C-S-H (Calcium- Silicate- Hydrate) gel formation is reducing. This was due to that silica in the foundry sand wasn't consumed to form calcium silicate hydrates.

5.2 Scope for further work

Although there is large scale availability of waste-foundry sand in the world such material is not commonly used in the concrete industry. Though waste-foundry sand has been investigated extensively as ingredient materials for medium strength concrete, and controlled low-strength materials, its possible utilization in high strength concrete has not been researched thoroughly. Not much work has been reported on the use of foundry sand in concrete and concrete related products like bricks, blocks and paving stones.

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