STRENGTH AND DURABILITY STUDIES OF CONCRETE CONTAINING WASTE FOUNDRY SAND

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CERTIFICATE

Certify that the thesis entitled "Strength and Durability Studies of Concrete Containing Waste Foundry Sand" which is submitted by Mr. Gurpreet Singh, in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Civil Engineering Department of Thapar University, Patiala is a record of the candidate's own independent and original research work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

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DECLARATION

I hereby certify that the work which is being presented in this thesis entitled “Strength and Durability Studies of Concrete Containing Waste Foundry Sand” being in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Civil Engineering submitted in Civil Engineering Department of Thapar University Patiala is an authentic record of my own work carried out under the supervision of Dr Rafat Siddique and refers other research’s work are duly listed in the reference section.

The matter presented in this thesis has not been submitted in part or full to any other university or institute for the award of any degree in India or abroad.

Gurpreet Singh.

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Gurpreet Singh.

(Gurpreet Singh)

ABSTRACT

Due to ever increasing quantities of waste materials and industrial by-products, solid waste management is the prime concern in the world. Scarcity of land-filling space and because of its ever increasing cost, recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal. There are several types of industrial by-products and waste materials. The utilization of such materials in concrete not only makes it economical, but also helps in reducing disposal concerns. One such industrial by-product is Waste Foundry Sand (SFS). WFS is major byproduct of metal casting industry and successfully used as a land filling material for many years. But use of waste foundry sand (WFS) for land filling is becoming a problem due to rapid increase in disposal cost. In an effort to use the WFS in construction materials, research has being carried out for its possible utilization in making concrete as partial replacement of fine aggregate. In India, approximately 1.71 million tons of waste foundry sand and in Punjab region, approximately 0.17 million tons of waste foundry is produced yearly.

This experimental investigation was performed to evaluate the strength and durability properties of M20 (30 MPa) and M30 (40 MPa) grades of concrete mixes, in which natural sand was partial replaced with waste foundry sand (WFS). Natural sand was replaced with five percentage (0%, 5%, 10%, 15%, 20%) of WFS by weight. A total of ten concrete mix proportions M-1, M-2, M-3, M-4 and M-5 for M20 grade of concrete and M-6, M-7, M-8, M-9 and M-10 for M30 grade of concrete with and without WFS were developed. Compression test, splitting tensile strength test and modulus of elasticity were carried out to evaluate the strength properties of concrete at the age of 7, 28, 91 and 365 days. In non destructive testing, rebound hammer and ultrasonic pulse velocity test were conducted at the age of 28, 91 and 365 days. In case of durability property, abrasion resistance, rapid Chloride Permeability and deicing salt scaling resistance was evaluated at the age of 28, 91 and 365 days. Statistical analysis and comparative study between strength and durability properties of both grade of concrete (M20 and M30) were carried out at the age of 28, 91 and 365 days. XRD study was done to identify the presence of various compounds in M20 grade of concrete with foundry sand in varying percentages replacement of fine aggregate.

Test results showed that there is increase in compressive strength, splitting tensile strength and modulus of elasticity for both grades of concrete mixes (M20 and M30) with inclusion of waste foundry sand (WFS) up to 15% replacement. Resistance of concrete against abrasion (wear), rapid chloride permeability and deicing salt scaling were also improved for both grades of concrete mixes. Quality of concrete in term of homogeneity and uniformity were also improved. Results showed that there was better enhancement in strength and durability properties at 15% replacement of fine aggregate with WFS.

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CHAPTER – 1

INTRODUCTION

1.1 GENERAL

Concrete is the most widely used man-made construction materials in the world. Slightly more than a ton of concrete is produced each year for every human being on the planet

Fundamentally, concrete is economical, strong, and durable. Although concrete technology across the industry continues to rise to the demands of a changing market place. The construction industry recognizes that considerable improvements are essential in productivity, product performance, energy efficiency and environmental performance. The industry will need to face and overcome a number of institutional competitive and technical challenges. One of the major challenges with the environmental awareness and scarcity of space for land-filling is the wastes/byproducts utilization as an alternative to disposal. Throughout the industrial sector, including the concrete industry, the cost of environmental compliance is high. Use of industrial by-products such as foundry sand, fly ash, bottom ash and slag can result in significant improvements in overall industry energy efficiency and environmental performance.

The consumption of all type of aggregates has been increasing in recent years in most countries at a rate far exceeding that suggested by the growth rate of their economy or of their construction industries. Artificially manufactured aggregates are more expensive to produce, and the available source of natural aggregates may be at a considerable distance from the point of use, in which case, the cost of transporting is a disadvantage. The other factors to be considered are the continued and expanding extraction of natural aggregates accompanied by serious environmental problems. Often it leads to irremediable deterioration of the country side. Quarrying of aggregates leads to disturbed surface area etc., but the aggregates from industrial wastes are not only adding extra aggregate sources to the natural and artificial aggregate but also prevent environmental pollution.

Foundry industry produces a large amount of by-product material during casting process. The ferrous metal casts in foundry are cast iron and steel, non ferrous metal are aluminum, copper, brass and bronze. Over 70% of the total by-product material consists of sand because moulds usually consist of molding sand, which is easily available, inexpensive, resistance to heat damage, easily bonded with binder, and other organic material in mould. Foundry industry use high quality specific size silica sand for their molding and casting process. This is high quality sand than the typical bank run or natural sand. Foundries successfully recycle and reuse the sand many times in foundry. When it can no longer be reused in the foundry, it is removed from the industry, and is termed as waste foundry sand (**WFS)**. It is also known as spent foundry sand (SFS) and used-foundry sand (UFS).

Waste foundry sand are by-products which appears to possess the potential to partially replace regular sand as a fine aggregate in concretes, providing a recycling opportunity for them. If such types of materials can be substituted partly/fully for natural sand (fine aggregates) in concrete mixtures without sacrificing or even improving strength and durability, there are clear economic and environmental gains. Currently, very limited literature is available on the use of these by-products in concrete. Waste foundry sand (WFS) is one of the major issues in the management of foundry waste. WFS are black in color and contain large amount of fines. The typical physical and chemical property of WFS is dependent upon the type of metal being poured, casting process, technology employed, type of furnaces (induction, electric arc and cupola) and type of finishing process (grinding, blast cleaning and coating).

1.2 TYPE OF WASTE FOUNDRY SAND

Classifications of foundry sand mainly depend primarily upon the type of binder and binder system used in metal casting. There are two types of foundry sand; Green sand (clay bonded) and chemically bonded. Resin coated sand, cold box sand, hot box sand and Co_2 sands are some common type of chemically bonded sand. (Mold and core test handbook, American foundry society).

1.2.1 Green (Clay Bonded) Sand

Green sand (clay bonded) is used for mould making and is mixture of silica sand (80-95%), bentonite clay (4-10%), carbonaceous additive (2-10%) and water (2-5%). Large portion of the aggregate is sand which can be either silica or olivine. There are many recipes for the proportion of clay, but they all strike different balance between moldability, surface finish and ability of the hot molten metal to design. It still remains very cheapest way to cast metal because of easy availability. Other minor ingredients are flour, cereals, rice hulls and starches. Silica sand is the bulk medium that resist the high temperature, bentonite clay bind the sand grain together, water activate the binding action of clay on sand and add plasticity. Carbonaceous additive prevent the fusing of sand on to the casting surface. Minor ingredients absorb moisture, improve the fluidity of sand. Green sand (clay bonded sand) also contains some chemical like Magnesium oxide (MgO), Potassium dioxide (K_2O), Titanium dioxide (TiO_2). About 85% of green sand molding used for cast iron in the world. Green sand is not green in color but green in the sense that it is used in a wet stage.

1.2.2 Chemically Bonded Sand

Chemically bonded sand is used in both core making and mould making. In core making, high strength is necessary to withstand against high temperature. Chemically bonded sand is mixing of silica sand and chemical binder (1-3%) for mould and core. When binder mixes with the silica sand, then catalyst start the reaction that cures the chemical resin and hardens the sand core or mould. There are various chemical binder system used in foundry industry, some of the binder are furfuryl alcohol, phenolic urethane, phenolic no bake-acid, phenolic resole-ester, sodium silicate, phosphate, alkyd (oil) urethane, shell liquid/powered and flake resins. Some of the most common chemically bonded sands are resins coated sand, hot box, cold box and Co_2 sand. Majority of binder used in the foundry are self setting chemical binder. The following sand binder or binder system in their sand mold process are Sodium silicate, phenolic urethanes, phenolic esters, phenolic hot box, phenolic nobake, furan nobake, furan warm box, sulphur dioxide, alkyd urethane and alkyd oil based core oil and epoxy SO_2. Colour of the chemically bonded sand is light than clay bonded sand.

1.3PROPERTIES OF WASTE FOUNDRY SAND

1.3.1 Physical Properties

Generally, waste foundry sand (WFS) is sub-angular to round in shape. Green sands are black or grey, whereas chemically bonded sands are of medium tan or off-white color. Grain size distribution of waste foundry sand is uniform with 85-95% of the material in between 0.6 mm to 0.15 mm and approximately 5 to 20% of foundry sand can be smaller than 0.075 mm. Dayton et al. (2010) mentioned that sand (0.05 to 2 mm) was the dominant size fraction in the 39 spent foundry sands ranging from 76.6% to 100% with a median of 90.3%.The specific gravity of foundry sand varies between 2.39 and 2.79. Waste foundry sand has low absorption capacity and is non-plastic. Physical properties of waste foundry as reported by Javed and Lovell (1994), Naik et al. (2001), Guney et al. (2010) and Siddique et al. (2011), are given in Table 1.1

Carey and Sturtz (1995) have reported that physical properties of WFS such as Particle gradation, fine contents, density, and absorption and specific gravity help to recognize its workability and suitability in flow able fill. Deng and Tikalsky (2008) have reported that variation in the density (1052–1554 kg/m^3), specific gravity (2.38–2.72) and absorption (0.38–4.15%) measurements may be attributed to the variation in sand mineralogy, particle gradation, grain shapes and fine contents. Good gradation and round shape lead to a compact structure and high density. Correlation of absorption with fine content and grain size can be interpreted by the law that a finer particle leads to a higher specific surface area, which favors the absorption of water.

Table 1.1: Typical Physical Properties of Waste Foundry Sand

Property	Javed and Lovell (1994)	Naik et al. (2001)	Guney et al. (2010)	Siddique et al. (2011)
Specific gravity	2.39-2.55	2.79	2.45	2.61
Fineness modulus	-	2.32	-	1.78
Unit Weight (kg/m^3)	-	1784	-	1638
Absorption (%)	0.45	5.0	-	1.3
Moisture content (%)	0.1-10.1	-	3.25	-
Clay lumps and friable particles	1- 44	0.4	-	0.9
Materials finer than 75µm (%)	-	1.08	24	18

1.3.2 Chemical Properties

Chemical composition of the waste foundry sand depends on the type of metal, type of binder and combustible used. The chemical composition of the foundry sand may influence its performance. Waste foundry sand is rich in silica content. It is coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins/chemicals) and dust. Silica sand is hydrophilic and consequently attracts water to its surface. Chemical composition of WFS as reported by American Foundryman's Society (1991), Guney et al. (2010), Etxeberria et al. (2010) and Siddique et al. (2011) is given in Table 1.2

Johnson (1981) indicated that depending on the binder and type of metal cast, the pH of waste foundry sand can vary between 4 and 8. It has been reported that some waste foundry sands can be corrosive to metals (MNR,1992). Due to the presence of phenols in foundry sand, it raises concerns that precipitation percolating through stockpiles could mobilize leachable fractions, resulting in phenol discharges into surface or ground water supplies.

Table 1.2: Chemical Composition of Foundry Sand

Constituent	**Value (%)**			
	American Foundryman's Society (1991)	Guney et al. (2010)	Etxeberria et al. (2010)	Siddique et al. (2011)
SiO_2	87.91	98	95.10	78.81
Al_2O_3	4.70	0.8	1.47	6.32
Fe_2O_3	0.94	0.25	0.49	4.83
CaO	0.14	0.035	0.19	1.88
MgO	0.30	0.023	0.19	1.95
SO_3	0.09	0.01	0.03	0.05
Na_2O	0.19	0.04	0.26	0.10
K_2O	0.25	0.04	0.68	-
TiO_2	0.15	-	0.04	-
Mn_2O_3	0.02	-		-
SrO	0.03	-		-
LOI	5.15	-	1.32	2.15

1.3.3 Mechanical Properties

Waste foundry sand has good durability properties as measured by low Micro-Deval abrasion (Ontario Ministry of Transportation, Canada 1996). Javed and Lovell (1994) have revealed relatively high soundness loss, which may be due to the samples of bound sand loss and not a breakdown of individual sand particles. The angle of shearing resistance (also known as friction angle) of waste foundry sand varies between 33 and 40 degrees, which is comparable to that of conventional sands. Typical mechanical properties of waste foundry sand are given in Table 1.3

Table 1.3: Typical Mechanical Properties of Spent Foundry Sand

Property	Results
Micro-deval abrasion loss (%) (MNR–1992)	< 2
Magnesium sulfate soundness loss (%)(MNR–1992)	5 - 15 6 - 47
Friction angle (deg)	33 - 40
California bearing ratio (%) (Javed and Lovell 1994)	4 - 20

1.3.4 Potential Contamination

Casting processes used in foundries involve a variety of sands, inorganic or organic binders and other additives, which generate residues in sand. The presence of these residues, mixing of waste sand with dust and other fine-grained foundry waste materials, limit the reuse of foundry sand. Foundries use screening systems and magnetic separators to segregate reusable sand from other wastes and to separate particles of varying sizes. By carefully monitoring the casting process and waste sand, foundries can ensure that their sand is largely free from excess contaminants and qualifies as a non-hazardous industrial by-product (FIRST, 2004).

The binder system is the primary source of organic contaminants in sand. Green sand casting, which generally does not involve the use of organic binders, has lower potential for leaching organic compounds than chemically bonded systems depending upon the curing and pouring process. The more reactive organic compounds commonly used in binders and resins are of special concern because they can be transformed into new hazardous compounds under incomplete combustion conditions. Testing has not indicated that these reactive compounds are found at significant concentrations in sand (FIRST–2004).

1.4 MANAGEMENT OPTION

In foundry processes, sand from collapsed moulds or cores can be reclaimed and then reused. Some new sand and binder is then added to maintain the quality of the casting and to make up for sand lost during normal operations (Javed and Lovell, 1994). Foundry sand is produced by different foundry classes. The ferrous foundries (gray iron, ductile iron and steel) produce the most sand and aluminum, copper, brass and bronze produce the rest. The sands from the brass, bronze and copper foundries are generally not reused. Little information is available regarding the amount of foundry sand that is used for purposes other than in-plant reclamation but waste foundry sand has been used as a fine aggregate substitute in construction applications and as kiln feed in the manufacture of Portland cement. Most of the waste foundry sand from green sand operations is land-filled, sometimes being used as a supplemental cover. Fiore and Zanetti (2007) studied the foundry sand reuse and recycling. They investigated the foundry sand of varying sizes. On the grounds of the gathered results, they concluded that residues may be divided in three categories according to the particle-size dimensions: below 0.1 mm, between 0.1 to 0.6 mm and above 0.6 mm. The fraction above 0.6 mm, mainly made of metallic iron, may be reused in the furnaces. The fraction between 0.1 mm to 0.6 mm may be reused in cores production after a regeneration treatment. The fraction between 0.1 to 0.025 mm may be recycled as raw material for the concrete industry and the below 0.025 mm fraction may be reused in green molding operations. An economic evaluation of the proposed reuse and recycling solutions was performed. Fig. 1.1 shows the recycling of foundry sand.

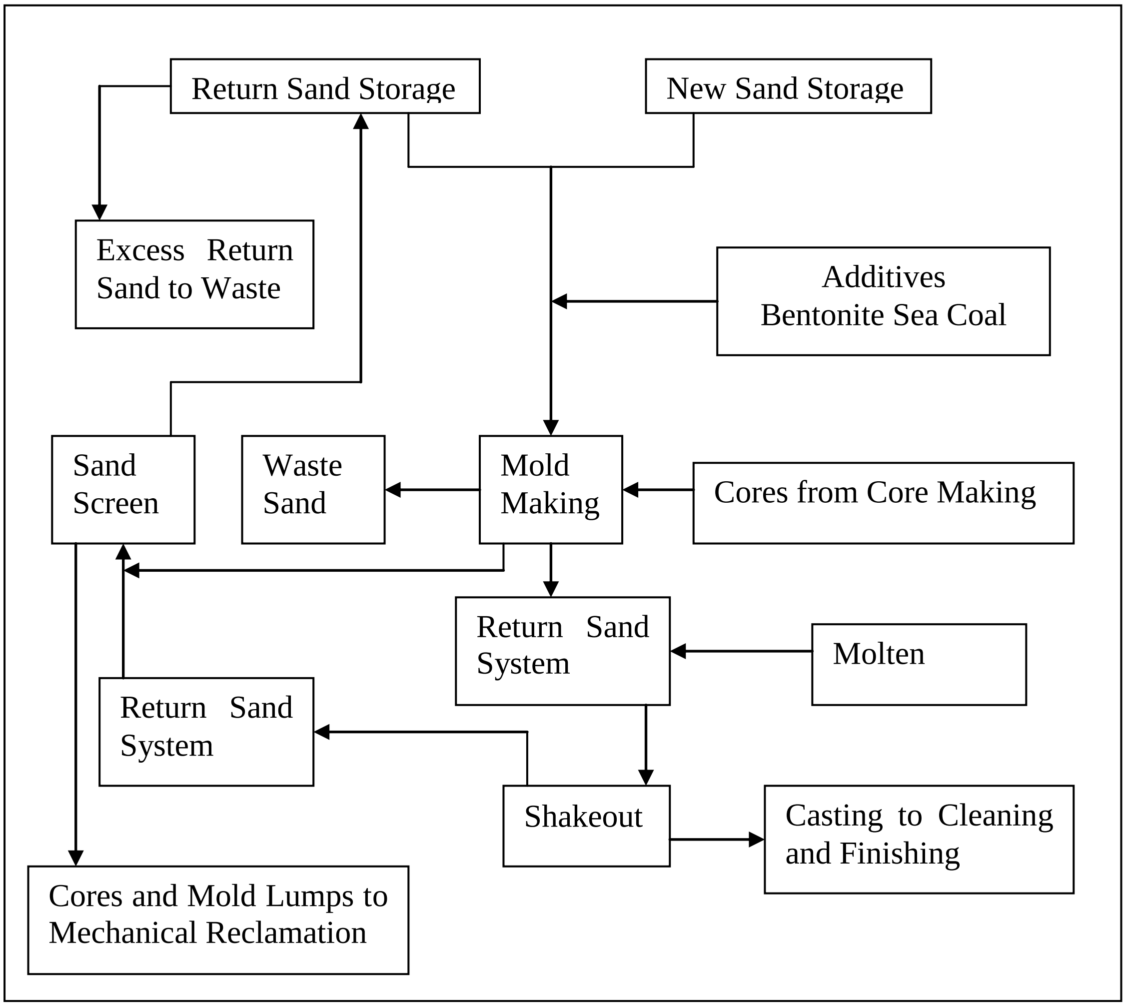


Fig.1.1: Recycling of Foundry Sand

1.5 RISK EVALUATION

Hindman et al (2008) conduct a green house experiment to determine the suitability of waste foundry sand from ferrous and non ferrous foundry in soil by measuring the plant growth, plant uptake and leaching of nutrient, trace metals, metalloids and organic. They observed that use of waste foundry sand in soil will not increase the risk of trace element or organic contamination transport to surrounding soil and water.

Dungan and Dees (2006) conducted a 28-day experiment with the earthworm Eisenia Fetida and 6 different waste foundry sands to assess the bioavailability of metals in soil blends up to 50% foundry sands. Based upon the earthworm mortality and metal accumulation data, the study suggests that waste sands from the iron, aluminum and steel foundries do not pose an ecotoxicological or metal transfer risk. However earthworms in soil blends using sands from a brass foundry suffered excessive mortality and metal uptake.

In 2002, in Unitted States, an effort to identify the risks and benefits of using foundry sand from ferrous and aluminum foundries was initiated. Partners in the effort included the US Department of Agriculture-Agricultural Research Service, the Ohio State University, the Pennsylvania State University and US EPA. Using the metal and organic constituent levels from foundry sands from more than 30 iron, steel, and aluminum foundries, EPA and USDA modeled several exposure pathways associated with the use of foundry sands in a soil blend. Exposure pathways included: inhalation, groundwater ingestion, and ingestion of vegetables grown in a home gardener scenario. The draft study concluded that non-olivine sands from iron, steel and aluminum foundries do not pose a threat to human health or the environment when used in roadway sub-base or as an ingredient in manufactured soils or soil-less media. The study was submitted for peer review and a final report is pending (US EPA 2010).

1.6 APPLICATIONS OF WASTE FOUNDRY SAND

Indian foundries produce approximately 1.71 million tons of waste foundry sand each year (Metal World, 2006). In United States of America, metal casting foundries dispose of approximately 9 million metric tons of waste foundry sand (WFS) in landfills in 2000 (Winkler and Bol’shakov, 2000). United States’s average land-filling tipping fee of foundry byproducts is US $15-75 per ton inclusive of storage, transportation and labour costs (Winkler et al. 1999). The annual cost of WFS disposal was around US $ 135- 675 million. The considerable disposal expense has made the current practice of WFS disposal in landfills less favorable. Besides the financial burden to the foundries, land-filling WFS also makes them liable for future environmental costs, remediation problems and regulation restrict ions. This issue is increasingly addressed by alternate options of reusing WFS beneficially. Waste foundry sand is made up of mostly natural sand material. Its properties are similar to the properties of natural or manufactured sand. Thus it can normally be used as a replacement of sand.

Beneficial reuses of WFS span a variety of applications related to infrastructure engineering and rehabilitation works. Some of the researchers have reported the possible use of waste foundry sand in different civil engineering applications, which are given in Table 1.4. These alternate applications offer cost savings for both foundries and user industries and an environmental benefits at the local and national level.

Table 1.4: Uses of WFS in Various Applications

Author's Name	Application
Javed and Lovell(1994), Traeger(1987), Kleven et al.(2000), MOEE(1993), AFS(1991), Abichou et al.(1998), Mast and Fox(1998), Kirk(1998) and Gunney et al.(2006)	Highway
. Nail et al. (2003; 2004), Tikalsky et al. (1998) and Siddique et al.(2008)	Controlled low strength materials
Dungan et al. (2006), Deng and Tikalsky (2008)	Geotechnical Field
Braham A. (2002)	Hot Mix Asphalt
Ham RK and Boyle (1981), Fero et al. (1986), Engroff et al. (1989), Siddique et al. (2010) and Dungan et al. (2009)	Leachate Characteristic
Seung-Whee and Woo-Keun(2006), Naga and El-Maghraby(2003), Pereiraa et al. (2006) and Quaranta et al. (2004)	Ceramic material
El Haggar and El Hatow(2009)	Manhole cover
Periraa et al. (2004)	Refractory Mortars
Colombo et al. (2003), Ferraris et al. (2001), Geo and Drummond (1999)	Interization and Reuse of Waste materials by Vitrification
Santurde et al. (2011)	Clay Brick

1.7 SIGNIFICANCE AND OBJECTIVE OF THE RESEARCH

1.7.1 Significance in Research Area

With ever increasing quantities of industrial byproducts and waste materials, solid waste management has become the principal environmental concerns in the world. Scarcity of land-filling space and due to its ever increasing cost, utilization/recycling of byproducts/waste has become an attractive alternative to disposal. Several types of byproducts and waste materials are generated. Each of these waste products has specific effects on the properties of cement-based materials. The utilization of such materials in concrete not only makes it economical, but also do help in reducing disposal problems. Reuse of bulk wastes is considered the best environmental alternative for solving the problem of disposal. One of such industrial byproducts is Waste foundry sand (WFS). Waste foundry sand is a by-product of ferrous and nonferrous metal casting industries. 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 as waste foundry sand.

1.7.2 Gap in the Research Area

The Indian metal casting is well established. Indian Foundry Industry is the 4th largest casting producer in the world (Metal World, 2006). There are more than 5,000 foundry units in India, having an installed capacity of approximately 7.5 million tons per annum. The majority (nearly 95%) of the foundry units in India falls under the category of small-scale industry (Metal World, 2007). These foundry units generate approximately 1710000t (1.71 million Tons) waste foundry sand per year (The Institute of Indian Foundry men). In Punjab region, there are approximately 750 foundries. The main clusters of foundries are Batala (450), Ludhiana (150) and Jalandher (150). Punjab region generate approx. 170000t (0.17 million tons) waste foundry sand per year.

Not much work has been reported on the use of waste foundry sand (WFS) in concrete. In the present research, experimental investigations will be carried out to investigate the effect of waste foundry sand (WFS) as partial replacement of fine aggregate on the strength and durability properties of concrete.

1.7.3 Objective of the Research Work

Keeping in mind the gap in the research area, the objective of this study is to determine the strength and durability properties of concrete of two Grades (20 and 30 MPa) of concrete containing WFS (0 to 20% at an increment of 5%) as partial replacement of fine aggregate. Following are the objectives of this study:

- Characterization (Physical and Chemical Properties) of waste foundry sand
- Study of strength properties such as compressive strength, splitting tensile strength and modulus of elasticity at the ages of 7, 28, 91 and 365 days
- Study of durability properties such as chloride permeability, abrasion resistance, and deicing salt scaling resistance at the ages of 28, 91 and 365 days
- Non-destructive testing (Rebound Hammer and USPV) on concrete cubes
- Comparative study of strength and durability properties results of both the grades of concrete containing waste foundry sand
- Statistical analysis of the results would be carried out

1.8 ORGANIZATION OF THE THESIS

The thesis consists in five chapters:

Chapter 1 introduces the need for concrete with industrial by-products; by products used i.e. foundry sand their types and beneficial uses and global production in brief of these by-products and the objectives of the present work.

Chapter 2 reviews the existing literature on the use of foundry sand in concrete, various fresh properties, strength and durability properties of concrete using waste foundry sand.

Chapter 3 details the materials used with their properties, initial mix design, casting of specimens for studying various properties and methodology adopted for testing of different properties.

Chapter 4 presents the results, and their analysis for the fresh properties, strength properties such as compressive strength, splitting tensile strength, modulus of elasticity and durability properties like abrasion resistance, deicing salt surface scaling and rapid chloride penetration resistance of the mixes with waste foundry sand along with the XRD to identify the presence of various compounds of the concrete with foundry sand in varying percentages replacement of fine aggregate.

Chapter 5 summarizes and concludes the findings of the study. Few recommendations for further studies are also discussed.

References are placed at the end.

1.9 SUMMARY

This chapter discusses about the (i) types, properties, uses and applications of WFS in civil engineering; (ii) risk evaluation of waste foundry sand; (iii) significance of this research work and the need to investigate the effect of waste foundry sand (WFS) as partial replacement of fine aggregate on the strength and durability properties of concrete was discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Due to ever increasing quantities of waste materials and industrial by-products, solid waste management is the prime concern in the world. Scarcity of land-filling space, because of its ever increasing cost, recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal. There are several types of industrial by-products and waste materials. The utilization of such materials in concrete not only makes it economical but also helps in reducing disposal concerns. Natural sand is getting depleted due to large scale construction. So it is important to find out an alternative of natural sand, which can be used as partial replacement of natural sand (fine aggregate). There are several types of waste material/byproducts, which have been explored for possible use in concrete as a partial replacement of fine aggregate. Such types of materials are coal bottom ash, recycled fine aggregate, sewage sludge ash, stone dust and glass cullet, and waste foundry sand, etc.

Celik et al. (1996), Sahu et al. (2003), Tripathy and Barai (2006) and Shi-cong et al (2009) have reported the use of stone dust (SD) as partial replacement of fine aggregate. Celik et al. (1996) reported that increasing the dust content up to 10% improve the compressive strength and flexure strength of concrete. Sahu et al. (2003) concluded that there is significant increase in compressive strength, modulus of rupture and split tensile strength of concrete when sand was partially replaced by stone dust up to 40 percent. Tripathy and Barai (2006) investigated the compressive strength of mortar made with crusher stone dust (CSD) under normal, hot water curing and autoclaving curing. They concluded that up to 40% cement replacement by crusher stone dust and autoclave curing of mortar mix, gave same or better compressive strength than the control mortar mix (without CSD and normal curing). Shi-cong et al (2009) investigated the properties of concrete with crushed fine stone (CFS), furnace bottom ash (FBA) and fine recycled aggregate (FRA) as a fine aggregate. The test results showed that when furnace bottom ash and CSD was used as a fine aggregate to replace natural aggregates, the concrete exhibited higher compressive strength, lower drying shrinkage and higher resistance to the chloride-ion penetration.

Cyr et al. (2007) used sewage sludge ash (SSA) in cement based materials. They observed that compressive strength of mortars containing 25% and 50% of SSA was always lower than those of reference mortars but it shown that SSA has a long term positive effect which might be related to a slight pozzolanic activity.

Aggerwal et al. (2007), Kim et al. (2011) and Bilir (2012) reported the effect of coal bottom ash as replacement of fine aggregate in concrete. Aggarwal et al. (2007) carried out experimental investigation to study the effect of bottom coal ash. Compressive strength, flexural strength and splitting tensile strength tests were carried out with 0% to 50% replacement. They concluded that compressive strength of concrete containing 50% bottom ash is acceptable for most structural application. Kim et al. (2011) investigated the mechanical properties of high strength concrete. The compressive strength was unchanged and the flexural strength of concrete almost linearly decreased as the replacement ratio of the fine bottom ash was increased. The modulus of rupture was decreased to 19.5% and 24.0% in accordance with 100% replacement of normal aggregates with coarse bottom ash (CBA). It was also found that compressive strength was not affected by the replacement of fine aggregate with CBA. Bilir (2012) investigated the effect of non-ground coal bottom ash (NGCBA) and non-ground granulated blast furnace slag (NGGBFS) on durability properties of concrete. He concluded that replacement of fine aggregate up to 40% NGGBFS and up to 30% NGCBA, concrete has very low chloride permeability.

Khatib (2005), Rakshvir and Barai (2006), Evangelista et al. (2007), Rao et al. (2007) and Soutsos et al. (2011) studied the properties of concrete incorporating recycled aggregate. Khatib (2005) used recycled fine aggregate to study mechanical properties. The fine aggregate in concrete was replaced with 0, 25, 50 and 100% recycled aggregate. Beyond 28 days of curing, the rate of strength development in concrete containing recycled aggregate was higher than that of the control mix indicating cementing action in the presence of fine recycled aggregate. Rakshvir and Barai (2006) studied on recycled aggregate based concrete. They studied various physical and mechanical properties of recycled concrete. It was observed that compressive strength showed a decrease up to 10% with the increase in recycled aggregate content.

Evangelista et al. (2007) concluded that the use of fine recycled concrete aggregates does not jeopardize the mechanical properties of concrete, for replacement ratios up to 30%. Rao et al. (2007) reported the use of aggregate from construction and demolition waste in concrete. They reported that the use of these waste is suitable for making good qualityconcrete. Soutsos et al. (2011) concluded that compressive and tensile splitting strength of paving blocks made with recycled demolition aggregate determined levels of replacement which produced similar mechanical properties to paving blocks made with newly quarried aggregates.

Park et al. (2004), Shayan et al. (2005) and Idir et al. (2011) studied the use of waste glass as a partial replacement of fine aggregate in concrete. Park et al. (2004) reported that compressive, tensile, and flexural strength of concrete containing waste glass aggregates demonstrated a decreasing tendency along with an increase in the mixing ratio of the waste glass aggregates. The concrete containing waste glass aggregates of 30% mixing ratio gave the highest strength properties. Shayan et al. (2005) concluded that strength gain was slower in glass powder bearing concrete up to 28 days, but at the age of 404 days all the mixtures exceeded the 40 MPa target and achieved about 55 MPa strength and glass powder also reduced the chloride ion penetrability of the concrete. Idir et al. (2011) investigated the pozzolanic properties of fine and coarse mixed glass cullet. The result showed that the pozzolanic activity increases with glass fineness. Due to this activity compressive strength of mortar is increased by 10%.

Aggarwal et al. (2006) investigated the use of fly ash, slag, silica fume and marble dust as replacement of cement on the compressive strength of cement mortar. The result showed that the replacement of various industrial wastes (up to 20%) improved the compressive strength of mortar.

Mishra et al. (1994) investigate the effect of blast furnace slag, fly ash and silica fume on permeability of concrete. Rapid chloride permeability test was performed to check the quality of concrete. They concluded that use of these waste in concrete decreased the permeability of concrete and increases the quality of concrete.

Cwirzen A. (2010) reported the effect of nano-materials on physical properties of cementations matrixes. The results showed that mechanical properties such as compressive and flexural strength can be increased up to 50% by addition of 0.23wt% of carbon nano-tubes. Carbon nano-tubes and carbon nano-fibres and/or nano-silica appeared to improve frost resistance. Other properties such as autogenous shrinkage decreased significantly after addition of carbon nano-fibres. Nano-silica enabled an immense densification of the hydrated binder matrix, which in turn improved for instance the durability and mechanical properties.

2.2 LITERATURE RELATED TO WASTE FOUNDRY SAND (WFS) IN CONCRETE

There is another industrial waste, which is called waste foundry sand (WFS). It is also known as spent foundry sand (SFS) and used-foundry sand (UFS). Use of waste foundry sand in concrete and concrete related products like bricks, blocks and paving stones has been reported by Khatib and Ellis (2001), Naik et al. (2003), Naik et al. (2004), Fiore and Zanetti (2007), Siddique et al. (2009; 2011), Etxeberria et al. (2010) and Guney et al. (2010). Bakis et al. (2006) reported the use of waste foundry sand (WFS) in asphalt concrete. In this section literature related to the, effect of waste foundry sand in concrete, is reported properties wise.

2.2.1 Workability (Slump)

Guney et al. (2010) studied the effect of waste foundry sand (WFS) on the slump of concrete. Fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. It was observed that waste foundry sand decreased the fluidity and the slump value of the fresh concrete. This may be probably due to the presence of clayey type fine materials in the waste foundry sand, which are effective in decreasing the fluidity of the fresh concrete

Etxeberria et al. (2010) determined the slump of concrete containing chemical foundry sand and green foundry sand. The mixture proportion on concrete made with chemical foundry sand was 300 kg cement, 447.5 kg foundry sand, 399.6 kg natural sand and 1150 kg coarse aggregates per cubic meter of concrete, with water/cement ratio of 0.61, whereas, proportion of concrete with green foundry sand was 300 Kg cement, 326 kg foundry sand, 458 kg natural sand and 1150 kg coarse aggregates with water/cement ratio of 0.69. Values of slump were 150 mm and 75 mm for concrete made with chemical foundry sand and green foundry sand respectively.

2.2.2 Water Absorption and Void Ratio

Guney et al. (2010) determined the water absorption and void ratio of concrete containing WFS as partial replacement of fine aggregates. Water absorption test for each mixture was conducted at the age of 28 and 56 days. It was observed that (i) water absorption of the concrete with 5% waste foundry sand are higher than that of the concrete without waste foundry sand at the age of 56 days; (ii) water absorption ratio decreased for the specimens having waste foundry sand of 10, and 15%. This may be explained as the usage of waste foundry sand decreases the voids in the concrete. Therefore water absorption values have tendency to decrease in the specimens with greater waste foundry sand than 5%; (iii) void ratio of the samples with and without waste foundry sand are similar to the water absorption test results. Greater than 5% replacement of waste foundry sand with fine sand, void ratio decreases for all ages.

2.2.3 Compressive Strength and Modulus of Elasticity

Khatib and Ellis (2001) studied the influence of three types of foundry sand as a partial replacement of fine aggregate on the compressive strength of concrete, up to the age of 90 days. Three types of sand used in foundries were; the white fine sand without the addition of clay and coal, the foundry sand before casting (blended) and the foundry sand after casting (waste). The standard sand (Class M) was partially replaced by (0, 25, 50, 75 and 100%) these sands. They concluded that (i) with the increase in the replacement level of standard sand with foundry sand, the strength of concrete decreased; (ii) the concrete containing white sand showed somewhat similar strength to those containing waste sand at all replacement levels; (iii) presence of high percentage of blended sand in the concrete mixture caused a reduction in strength as compared with concrete incorporating white sand or waste sand; (iv) increase in strength was not observed at low replacement levels (less than 50%).

Naik et al. (2003) performed an investigation to develop technology for manufacturing cast-concrete products using Class F fly ash, coal-combustion bottom ash, and used-foundry sand. A total of 18 mixture proportions with and without the by-products were developed for manufacture of bricks, blocks and paving stones. Replacement rates, by mass, for sand with either spent foundry sand or bottom ash were 25 and 35%. Analysis of test data revealed that bricks with up to 25% replacement of cement and blocks with up to 25% replacement of cement and sand with recycled materials are suitable for use in both cold and warm climates. Other bricks and blocks were appropriate for building interior walls in cold regions and both interior and exterior walls in warm regions. For brick and paving stone, compressive strength was measure at the ages of 5, 28, 56, 91 and 288 days whereas for blocks, it was done at the ages of 7, 14, 28 and 91 days. They concluded that;

(i) Bricks with partial replacement of cement with fly ash (FA) showed slightly higher strength than the control while considerable reduction in strength was observed when a part of sand was substituted with bottom ash (BA). This was attributed to the lower strength of porous BA compared to sand. Substitution of part of the sand with spent foundry sand in brick mixes caused a small reduction in strength. All mixes, except for those with partial substitution of sand with BA, met the compressive strength requirement of ASTM C 55 for Grade N (24MPa) bricks from about three to 18 days of age. Mixes containing BA met the strength requirement for Grade S (17MPa) bricks from the age of about 18 days.

(ii) All the paving stone mixes showed considerable strength gain with time. Paving stones with FA showed higher strength than the control mix throughout the test. Partial replacement of sand with BA caused a large reduction in compressive strength. Unlike bricks and blocks, partial replacement of sand with SFS, as in paving stones caused considerable reduction in strength. Overall, none of the paving stones met the compressive strength requirement of ASTM C 936 for solid concrete paving units (55MPa).

(iii) All the block mixes except the one exceeded minimum compressive strength requirement of ASTM C 90 (13MPa).

(iv) Up to 25% of sand in blocks could be replaced with either BA or SFS in cold regions; and up to 35% of sand in bricks and blocks could be replaced with either BA or SFS for use where frost action is not a concern.

Naik et al. (2004) investigated the effect of waste foundry sand on the compressive strength of wet-cast concrete bricks and paving stones. It was observed that (i) wet-cast bricks that meet the minimum compressive strength requirement of ASTM C 55 for Grade N (min. strength 24 MPa) could be produced with concrete (having strength as low as 14 MPa cylindrical strength) containing spent foundry sand; (ii) wet-cast paving stone that meet the minimum strength requirement of ASTM C 936 (min. strength 55 MPa) could be produced with concrete (having strength as low as 40 MPa cylindrical strength) containing spent foundry sand.

Siddique et al. (2009) investigated the effect of waste foundry sand (WFS) as partial replacement of fine aggregate on the compressive strength and modulus of elasticity of concrete. Compressive strength and modulus of elasticity of concrete mixtures made with and without foundry sand was determined at 7, 28, 56, 91, and 365 days of curing. They concluded that (i) there was marginal increase in the compressive strength of concrete mixtures with the inclusion of foundry sand as partial replacement of regular sand. At 28 days, Control Mixture M-1(0% WFS) achieved a compressive strength of 28.5 MPa, whereas Mixtures M-2 (10% FS), M-3 (20% FS), M-4 (30% WFS) 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% WFS). Compressive strength of concrete mixtures also increased with age. With the increase in age (from 56 to 365 days), percentage increase in compressive strength for control mixture (0% WFS) was between 8 to 18%, between 11.4 to 18.8% for mixture M-2, between 12 to 20% for mixture M-3, and between 12.4 to 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 foundry sand could probably be due to the fact that foundry sand was finer than regular sand which resulted in the denser concrete matrix and also due the silica content present in the foundry sand. Javed and Lovell (1994) reported similar results, wherein they concluded that used foundry sand can be suitably used as partial replacement of fine aggregates without affecting the performance of asphalt concrete. In this research also, inclusion of foundry sand has not adversely affected the 28-day compressive strength of concrete mixtures made with foundry sand but has shown an increase between 4.2 to 9.8% depending upon the foundry sand content. Increase in the compressive strength of concrete mixes incorporating waste foundry sand indicated that foundry sand could be successfully used in making concrete as partial replacement of fine aggregate. Foundry sand marginally enhanced the modulus of elasticity of concrete mixtures. At 28-day, Control Mixture M-1 (0% WFS) achieved a modulus of elasticity of 25.1 GPa, whereas Mixture M-2 (10% WFS), M-3 (20% WFS) and M-4 (30% WFS) achieved a modulus of elasticity of 26.75, 27.60, and 28.4GPa respectively. It is also evident that modulus of elasticity of all mixtures continued to increase with age. Increase in modulus of elasticity varied between 5.2 to 12% depending upon foundry sand content and age of testing.

Guney et al. (2010) examined the influence of inclusion of WFS as partial replacement of fine aggregates on the compressive strength and modulus of elasticity of concrete up to the age of 56 days. Fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. It was observed that the concrete with 10% waste foundry sand replacement exhibited highest compressive strength at the age of 56 days. Compressive strength decreased with an increasing amount of foundry sand. The concrete with 10% waste foundry replacement may indicate the optimum reallocation amount of waste foundry sand. The concrete with 10% waste foundry sand shows almost the same strength of control concrete mixture; whereas the other entire waste foundry added mixtures exhibit lower values than that of the control. This may indicate that the particle size distribution of the mixture with 10% waste foundry sand has sufficient adherence than the other mixtures with waste foundry sand. On the other hand, it is obvious that static modulus of elasticity is a function of the compressive strength of concrete. If the compressive strength of concrete increases then static modulus of elasticity also increases and vice versa.

Etxeberria et al. (2010) studied the effect of two types of foundry sands on the 28-day compressive strength and modulus of elasticity of concrete. Types of foundry sand used were chemical foundry sand and green foundry sand. The mix proportion of concrete made with chemical foundry sand was 300 kg cement, 447.5 kg foundry sand, 399.6 kg natural sand and 1150 kg coarse aggregates per cubic meter of concrete, with water/cement ratio of 0.61 and concrete mixture with green foundry sand was 300 kg cement, 326 kg foundry sand, 458 kg natural sand and 1150 kg coarse aggregates with water/cement ratio of 0.69. Test results indicated that concrete with chemical foundry sand achieved 28-day strength of 28.4 MPa, where as it was 25 MPa for green foundry sand concrete. Modulus of elasticity values at 28 days were 27.92 GPa and 27.39 GPa for concrete incorporating chemical foundry sand and green foundry sand, respectively.

2.2.4 Splitting Tensile Strength

Bakis et al. (2006) explored the possible use of waste foundry sand (WFS) in asphalt concrete. In asphalt Concrete mixtures, fine aggregates were replaced with 0, 4, 7, 10, 14, 17 and 20% WFS. Indirect tensile strength tests were conducted as per AASTHO (1989). As the percentage of WFS was increased, the strength of the asphalt concrete mixtures linearly decreased, yielding values from 1.39 MPa with 0% WFS to 0.94 MPa with 20% WFS.

Siddique et al. (2009) determined the effect of waste foundry sand (WFS) as partial replacement of fine aggregate on the splitting tensile strength of concrete. The splitting tensile strength of concrete mixtures made with and without foundry sand was measured at the ages of 7, 28, 56, 91 and 365 days. The variation in the splitting-tensile strength with foundry sand content was similar to that observed in case of the compressive strength. Splitting-tensile strength of concrete mixtures increased with the increase in foundry sand content. At 28-day, splitting tensile strength of control mixture M-1 (0% WFS) was 2.75 MPa, whereas mixtures M-2 (10% WFS), M-3 (20% WFS) and M-4 (30% WFS) achieved strength of 2.85, 2.9 and 3.0 MPa respectively; a marginal increase of 3.6, 5.4 and 9% in comparison with the strength of the control mixture M-1 (0% WFS). Splitting tensile strength was found to increase with age. At 56-day, mixtures M-1 (0% WFS), M-2 (10% WFS), M-3 (20% WFS) and M-4 (30% WFS) 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. 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 (0% WFS) was between 6.5 to 12.7%, 8.7 to 13% for mixture M-2, 9.3 to 14.5% for mixture M-3 and 8 to 15% for mixture M-4.

Guney et al. (2010) determined the splitting tensile strength of concrete made with WFS as partial replacement of fine aggregates. 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 control mix (without foundry sand).

Etxeberria et al. (2010) investigated the effect of chemical foundry sand and green foundry sand on the 28-day splitting tensile strength of concrete. The mix proportion on concrete made with chemical foundry sand was 300 kg cement, 447.5 kg foundry sand, 399.6 kg natural sand and 1150 kg coarse aggregates per cubic meter of concrete, with water/cement ratio of 0.61, where was proportion of concrete mixture with green foundry sand was 300 kg cement, 326 kg foundry sand, 458 kg natural sand and 1150 kg coarse aggregates with water/cement ratio of 0.69. Test results indicated that both concretes made with chemical foundry sand and green sand achieved same strength (2.9 MPa).

2.2.5 Flexural Strength

Siddique et al. (2009) investigated influence of foundry sand (FS) as partial replacement of fine aggregate on the flexural strength of concrete. The flexural strength of concrete mixtures made with and without foundry sand was measured at the ages of 7, 28, 56, 91 and 365 days. Like compressive and splitting-tensile strength, flexural strength of concrete mixtures increased marginally with the increase in foundry sand content. At 28-day, splitting-tensile strength of Control Mixture M-1 (0% WFS) was 3.41 MPa whereas Mixtures M-2 (10% WFS), M-3 (20% WFS) and M-4 (30% WFS) achieved strength of 4, 4.1, and 4.18 MPa respectively; an increase of 2.0%, 5.6% and 9% in comparison with the strength of the Control Mixture M-1 (0% WFS). From these results, it is also evident that flexural strength increased with the age. Between 28 and 365 days, control mixture M-1 (without WFS) achieved an increase of 7.3 to 13.2%, whereas increase was between 10.6 to 14.9% for mixture M-2 (10% WFS), 7 to 10.8% for mixture M-3 (20% WFS) and 7.1 to 12.3% for mixture M-4 (30% WFS).

2.2.6 Freezing and Thawing Resistance

Naik et al. (2003) studied the effect WFS on the freezing and thawing (F&T) resistance of bricks, paving stones and blocks. Tests were performed according to ASTM C 1262. Freezing and thawing tests on bricks and paving stones were started at the age of 74 days and for blocks, it was 154 days. Based on the test results, they reported that (i) brick mixtures reached the critical value (0.2%) of weight loss at about 92, 150, 30, 18, 40 and 12 cycles of F&T respectively. Partial substitution of sand with WFS caused a sharp drop in F&T life of bricks, in spite of its nearly negligible effect on strength, density, and absorption. This might have something to do with the nature of the WFS. Weight loss of roughly 0.2% based on estimated initial oven-dry weight of the paving stones was taken as a critical value; (ii) In case of paving stone; all mixtures reached the critical value of weight loss (0.2%) at about 190, 200, 150, 120, 95 and 45 cycles of F&T respectively. Overall, the F&T life of the paving stones was about 2.3 times that of the bricks. This was attributed to the lower water-cementitious materials ratio of paving stones, which resulted in higher values of compressive strength compared to bricks. Partial replacement of sand with WFS resulted in large reduction in F&T life of paving stones. The very large decrease in F&T life of paving stones containing SFS could be attributed to the plastic and slippery nature of moist SFS; and (iii) Blocks of all mixtures reached the critical value of weight loss at about 250, 350 (estimated by extrapolation), 200, 10, 170, and 30 cycles, respectively. Blocks with 25% replacement of sand with SFS showed a large reduction in F&T life compared to FA. Blocks with 35% replacement of sand with either BA or WFS showed a very sharp reduction in F&T life compared with FA. Although the strength of blocks containing WFS was considerably higher than that of blocks containing BA, the F&T lives of the two groups of blocks were about the same.

Naik et al. (2004) conducted tests for freezing and thawing resistance of bricks and paving stones in accordance with ASTM C 140. The test procedure involved water saturated brick and paving stone specimens, each with a 10mm layer of one bearing surface immersed in water subjected to cycles of freezing to -17°C and thawing to 24ºC and the mass of each specimen determined. The resistance to cycles of freezing and thawing decreased with increasing amounts of the three byproduct materials (fly ash, bottom ash and waste foundry sand in case of bricks. In case of paving stones the wet-cast paving stones made with control mix showed a significant amount of mass loss due to surface scaling between 60 to 150 cycles of freezing and thawing.

2.2.7 Drying Shrinkage

Khatib and Ellis (2001) investigated the influence of waste foundry sand as a partial replacement of fine aggregate on the drying shrinkage of concrete. Three types of sand used in foundries were considered, the white fine sand without the addition of clay and coal, the foundry sand before casting (blended) and the foundry sand after casting (waste). The standard sand (Class M) was partially replaced by (0, 25, 50, 75 and 100%) these types of sand. Concrete shrinkage up to 60 days was determined. Based on the test results they concluded that (i) length change of concrete increased as the replacement level of standard sand with the three types of sand increased; (ii) drying shrinkage values were higher in concrete containing waste sand and lower in concrete containing white sand; (iii) expansion was generally lower in concrete containing white sand as compared with the other two types (blended and waste) at a low sand replacement level of 25%.

Naik et al. (2003) measured the drying shrinkage of bricks and blocks containing waste foundry sand (WFS). The tests were conducted at the age of 300 days for bricks and at 270 days for blocks in accordance with ASTM C 426. They concluded that (i) drying shrinkage values of all the brick mixtures were about 0.023, 0.041, 0.031, 0.034, 0.041 and 0.036% respectively; (ii) bricks containing fly ash, bottom ash and waste foundry sand shrunk more than the control bricks upon drying. Overall, bricks with WFS shrunk more than those with BA. However, all the bricks met the maximum drying shrinkage requirement of ASTM C 55 (0.065%). While the drying shrinkage values for all blocks were 0.023, 0.020, 0.031, 0.028, 0.038 and 0.040% respectively. Blocks containing either BA or WFS shrunk more than the control upon drying. As in the case of bricks, blocks with WFS shrunk more than those with BA. However, all the blocks met the maximum drying shrinkage requirement of ASTM C 90 (0.065%).

2.2.8 Abrasion Resistance

Not much work has been reported on abrasion resistance of concrete containing waste foundry sand. However, Nail et al. (1997) carried out experiments on non air entrained concrete and air entrained concrete. The abrasion resistance of non air entrained concrete containing fly ash and used foundry sand exhibited less than 2.0 mm depth of wear at 60 minutes of abrasion per ASTM C 944 is considered to have adequate resistance to abrasion. In general, inclusion of used foundry sand and fly ash caused a reduction in the concrete resistance to abrasion. However, the maximum depth of abrasion for the 45% used foundry sand and 34% fly ash mixture was only 1.9 mm, while other mixtures exhibited less than 1.4 mm, for the 60-minute abrasion cycle, thus all mixtures with and without foundry sand/fly ash exhibited excellent resistance to abrasion. At the age of 182 days all concrete mixtures containing fly ash and used foundry sand showed an increase in resistance to abrasion compared with the 28-day age results. The maximum depth of abrasion was 1.4 mm, occurred in the 45% used foundry sand and 34% fly ash concrete mixture.

At the age of 28 days air-entrained concrete mixtures A6 (40% fly ash, 43% used foundry sand) and A7 (40% fly ash, 47% used foundry sand) were found to be less resistant to abrasion compared to other air entrained concrete mixtures. Irrespective of used foundry sand and fly ash content, all air entrained mixtures displayed high resistance to abrasion. They all passed ACI/ASTM accepted criteria. The depth of wear at 60 mints was 1.2 mm observed for the control mixtures while the other concrete mixture showed about 2.3 mm or less depth of wear at the age of 28 days. A similar trend was also observed at the age of 182 days. Abrasion resistance for the A6 and A7 concrete mixtures improved. Mix A-6 had a maximum depth of abrasion of 2.0 mm while Mix A-7 improved to 1.7 mm. Thus, all air entrained concrete mixtures exhibited very good resistance to abrasion regardless of used foundry sand content.

2.2.9 Deicing Salt Surface Scaling

The effect of WFS on deicing salt surface scaling resistance is not available in the literature. Therefore in this section the literature related to deicing salt surface scaling resistance of concrete is presented, to have an idea as to how the concrete responds to deicing salt surface scaling.

Fagerlund (1974; 1977) developed a testing concept in which the critical degree of saturation serves as a criterion to evaluate the potential frost resistance of concrete. The critical degree of saturation is the moisture content at which marked damage occurs to concrete during the freeze-thaw test. According to this concept, if the critical degree of saturation was known from the capillary absorption rate, it was possible to predict the number of cycles after which this saturation level was reached. Basheer (1991) obtained a very good correlation between the water permeability index and the weight loss due to freezing and thawing.

Marchand et al. (1995) concluded that saturated concrete exposed to repeated freezing and thawing cycles can be affected by two types of deterioration: internal micro cracking and de-icer salt scaling (also known as surface scaling). It has also been shown that, in practice, each phenomenon can occur independently of the other.

Jacobsen and Sellevold (1996) investigated the self healing of concretes deteriorated by internal cracking in the ASTM C666 procedure. Six different well cured concretes were deteriorated to various degrees. Then the specimens (concrete beams) were stored in water for 2-3 months. Resonance frequency, weight, volume and compressive strength were measured during deterioration and self healing. Concretes that lost 50% of their initial relative dynamic modulus during freeze/thaw could recover almost completely during subsequent storage in water, somewhat varying with concrete composition and degree of deterioration. Compressive strength showed reductions of 22 to 29% on deterioration, but only 4 to 5% recovery on self healing. Freeze/thaw tests on deteriorated and self-healed specimens in partly sealed condition showed clearly that the deterioration was governed by the ability to take up water; the more water that leaked through the plastic foil during freeze/thaw, the larger the deterioration.

Bouzoubaa et al. (2001) studied the durability of the concrete to the repeated cycles of freezing and thawing was determined from changes in length, mass, resonant frequency and pulse velocity of the test specimens before and after the freezing and thawing cycling and by calculating the durability factors. At the end of the 300 freezing and thawing cycling, the flexural strength of the control and test prisms was also determined. The test data indicated that all the test prisms had excellent performance in freezing and thawing cycling with durability factors ranging from 95 to 102. The residual flexural strength of the prisms also demonstrated good resistance of the concrete to the freezing and thawing cycling with values ranging from 72.6% to 93.0% of the control prisms.

2.2.10 Chloride Penetration

Chloride penetration into concrete from sea water or deicing salts is the most important, and most complicated, process that initiates reinforcement corrosion. It is only the chloride penetrations process but also the corrosion threshold level that has to be predicted to estimate the initiation time. Chloride moves into concrete in several ways. In concrete members submerged in sea water only pure diffusion occurs, except for the first month or so when certain convection may contribute. Convection of chlorides is a process where chlorides move with the moving pore water. When and where part of the pore water evaporates, the chlorides concentrate. In a splash zone where the chloride and moisture conditions at the concrete surface vary with time, leaching of chlorides must also be taken into account continuously when the concentration of free chlorides in the concrete is higher than in the surrounding sea water and during those periods when the concrete surface is washed by rain. The chloride penetration process is so far mainly predicted in concrete submerged in sea water, i.e. where the boundary conditions are simple and well known. The pure chloride diffusion process with constant boundary conditions, however, is still not fully understood and prediction models are still not accurate enough to predict the chloride profiles measured in structures.

Chloride in concrete may be present in either of the following forms

(i) Acid soluble chloride, which is equal to the total amount of chloride present in the concrete.

(ii) Bound chloride, which is the sum of chemically bound chloride with hydration products of the cement, such as the C_3A (Tricalcium aluminate) or C4AF (Tetracalcium aluminoferrite) phases and loosely bound chloride with C-S-H gel.

(iii) Free or water-soluble chloride, which is the concentration of free chloride ions (Cl) within the pore solution of concrete and is extractable in water under defined conditions. It is generally recognized that only the ‘‘free chloride’’ ions influence the corrosion process. It is reported that the resistivity decreases and corrosion rate increases with an increase in the chloride content.

Naik et al. (1997) investigated the resistance to chloride-ion penetration of non-air and air entrained concrete mixtures. They concluded that reference Mix NA-1 showed moderate chloride-ion penetration at the age of 56 days. Use of used foundry sand and fly ash improved chloride-ion penetration resistance of concrete. The chloride-ion penetration decreased from moderate to low when used foundry sand content was increased up to 20% and fly ash increased up to 34% at the age of 56 days. A similar trend was observed at the age of 182 days. The control mixture showed low chloride-ion penetration while mixtures with up to 20% used foundry sand and 34% fly ash improved to very low. The improved performance of used foundry sand/fly ash concrete mixture was associated with improved density of concrete micro-structure resulting from formation of pozzolanic reaction of fly ash and the finer used foundry sand. In general, all concrete with used foundry sand performed equivalent to or better than no-foundry sand concrete.

Similar results obtained for non-air entrained concrete. At the age of 56 days addition of used foundry sand and fly ash to the concrete improved the resistance to chloride. At the age of 182 days, all concrete mixtures, except one, had very low chloride permeability rating. The mixture containing 43% used foundry sand and 40 % fly ash had only a slightly lower resistance to chloride penetration and was rated low.

Schutter and Audenaert, (2004) also reported the effect of water absorption by immersion on chloride migration with conclusion that water absorption by immersion is not a reliable parameter for the estimation of chloride migration. They made the correlation between compressive strength and chloride migration at the age of 28 days. The obtained correlation values are rather low. Although some general trend might be noticed when comparing chloride migration with compressive strength, this approach was criticized fundamentally.

2.3 SUMMARY

Literature on the utilization of waste foundry sand in concrete is not extensive. Only few studies have been reported on the strength and durability properties of concrete. Therefore, present study is important and its findings will be very useful in concrete technology area, wherein, fine aggregates are to be replaced with industrial byproducts in making structural grade concrete.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 GENERAL

The chapter describes the details of experimental programs for the measurements of fresh properties, strength properties (compressive strength, splitting tensile strength and modulus of elasticity) and durability properties such as abrasion resistance, deicing salt surface scaling and rapid chloride permeability of concrete mixes made with varying percentages of waste foundry sand as partial replacement of fine aggregates.

3.2 MATERIALS USED

3.2.1 Cement

Portland pozzolana (fly ash based) cement was used. It was tested as per Indian standard specification (BIS-1489 part 1:1991). Test results are given in Table 3.1.

Table 3.1: Physical Properties of Portland Pozzolana Cement

Physical Properties	**BIS-1489:1991**	**Test Result**
Soundness Le-chat expansion	10.0 Max	1.6
Setting time (mm)		
Initial	30 Min.	92
Final	600 Max	248
Compressive Strength (MPa)		
3 day	16	18
7 day	22	36
28 day	33	47.8
Specific gravity	–	3.07
Standard Consistency (%)	–	35%
Drying shrinkage (%)	0.15 Max	0.024

3.2.2 Fine aggregates

Locally available natural sand with 4.75mm maximum size was used as fine aggregate. Its physical properties and sieve analysis are given in Tables 3.2 and Table 3.3 respectively.

Table 3.2: Physical Properties of Fine Aggregate

Sr.No.	***Properties***	**Observed values**
1.	Bulk Density (Loose), kg/m^3	1690
2.	Bulk Density (Compacted), kg/m^3	1890
3.	Specific Gravity	2.68
4.	Water Absorption (%)	1.2
5	Moisture content (%)	0.16
6	Material finer than 75µ (%)	0.5

Table 3.3: Sieve Analysis of Fine Aggregates

Weight of the sample taken = 1.0 kg

I.S. Sieve Size	**Weight retained in grams**	**Percentage weight retained in grams**	**Cumulative percentage of weight retained**	**Percentage passing**	**IS: 383-1970 Requirement for Zone II**
10.0mm	00	00	00	100	100
4.75mm	10	1.0	1.0	99	90-100
2.36mm	62	6.2	7.2	92.8	75-100
1.18mm	235	23.5	30.7	69.3	55-90
600µm	170	17	47.7	52.3	35-59
300µm	338	33.8	81.5	18.8	8-30
150µm	145	14.5	96.0	4.0	0-10
Pan	40	4	100	0	--

Fineness modulus of fine aggregate = 2.64

The sand conforms to grading zone II as per BIS: 383-1970

3.2.3 Coarse aggregates

Crushed stone with maximum 12.5mm graded aggregates (nominal size) were used. Physical properties and sieve analysis results are given in Tables 3.4 and Table 3.5 respectively.

Table 3.4: Physical Properties of Coarse Aggregates

Properties	Observed values
Maximum size (mm)	12.5
Bulk Density (kg/m^3)	1650
Specific Gravity	2.7
Total Water Absorption (%)	1.14
Moisture content (%)	Nil

Table 3.5: Sieve Analysis of Coarse Aggregates

Weight of the sample taken = 2.0 kg.

I.S. Sieve Size	Weight retained in grams	Percentage weight retained in grams	Cumulative percentage of weight retained	Percentage passing	BIS: 383-1970 Requirement
80mm	00	00	00	100	----
40mm	00	00	00	100	----
20mm	00	00	00	100	----
12.5mm	0.97	4.8	4.8	95.2	90-100
10mm	642	32.1	36.9	63.1	40-85
4.75mm	1184	59.2	96.1	3.9	0-10
pan	77	3.85	100	00	----

Fineness modulus of coarse aggregate = 6.35

Coarse aggregates conformed to BIS: 383- 1970.

3.2.4 Foundry Sand

Foundry sand obtained from Insaf foundry, Model Town, Mandi Gobindgarh, Punjab was used. The physical, chemical properties and sieve analysis of foundry sand are given in the Tables 3.6, 3.7 and 3.8 respectively. Particle size analysis of waste foundry sand is shown in Fig. 3.1

Table.3.6: Physical Properties of Foundry Sand

Sr. No.	Properties	Observed Values
1.	Color	Grey (Blackish)
2.	Bulk Density (Loose), kg/m^3	1336
3.	Bulk Density (Compacted),	1638
4.	Specific Gravity	2.18
5	Fineness Modulus	1.89
6	Water absorption (%)	0.42
7	Moisture Content (%)	0.11
8	Material Finer than 75µ (%)	8

Table.3.7: Chemical Properties of Foundry Sand

Constituents	% by Weight (Used in present study)
Silica (SiO_2)	83.8
Iron Oxide (Fe_2O_3)	5.39
Alumina (Al_2O_3)	0.81
Calcium Oxide (CaO)	1.42
Magnesium oxide (MgO)	0.86
Titanium Dioxide (TiO_2)	0.22
Sodium Oxide (Na_2O)	0.87
Potassium Oxide (K_2O)	1.14
Sulphur Trioxide (SO_3)	0.21
Manganese Oxide (Mn_3O_4)	0.047
Strontium Oxide (SrO)	Nil

Table.3.8: Sieve Analysis of Waste Foundry Sand

Weight of the sample taken = 1.0 kg

I.S. Sieve Size	Weight retained in grams	Percentage weight retained in grams	Cumulative percentage of weight retained	Percentage passing
4.75mm	00	00	00	100
2.36mm	11	1.1	1.1	98.9
1.18mm	15	1.5	2.6	97.4
600μm	25	2.5	5.1	94.9
300μm	791	79.1	84.2	15.8
150μm	122	12.2	96.4	3.6
Pan	36	3.6	100	00

Fineness modulus of waste foundry sand = 1.89

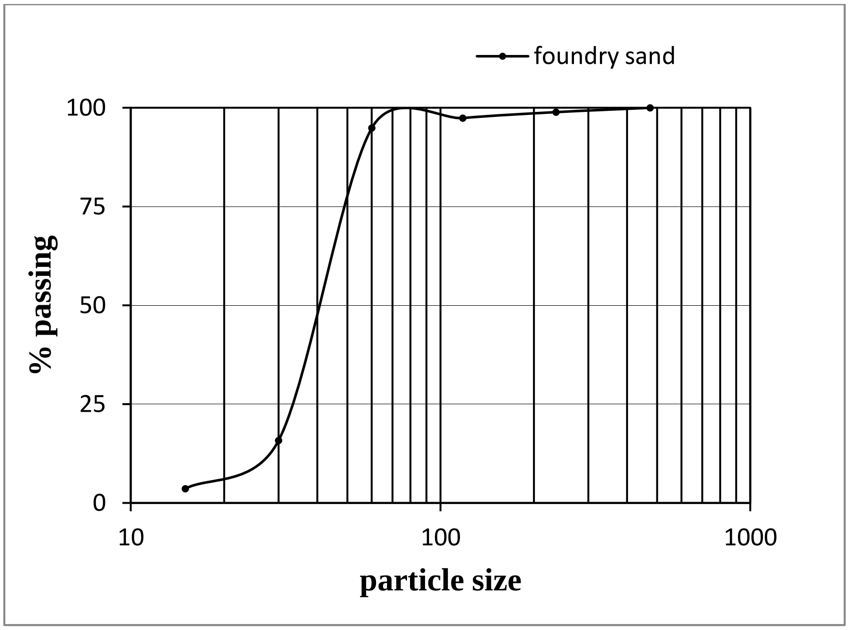


Fig. 3.1 Particle Size Analysis of Waste Foundry Sand

3.2.5 Superplasticizer

It was observed that increase in waste foundry sand content in concrete mixes lead to decrease the slump value of concrete. It could be due to the increase in fine particle of WFS in concrete mixes lead to increase the surface area of the fine aggregate with constant water cement ratio. To maintain the slump value, a polycarboxylic ether based superplasticizer (Sika viscocrete-10R) of SIKA brand complying with BIS: 9103–1999 was used. Specifications of superplasticizer are given in Table 3.9

Table 3.9: Specifications of Superplasticizer

Basis	Aqueous solution of modified polycarboxylate
Appearance	Brown liquid
Density	1080g/l at 30°C
pH	Approx. 5.0

3.2.6 Water

Water used for casting specimens conformed to the requirements of BIS: 456-2000. Test results are given in Table 3.10

Table 3.10: Properties of Water

Properties	Observed value
pH	8.0
Dissolved Solids (mg/l)	290
Suspended Solids	Nil
Chlorides (mg/l)	20
Sulphates (mg/l)	74
MPN Value/100 ml.	Nil

3.3 METHODOLOGY ADOPTED FOR MIX DESIGN

Mix design is a process of selecting suitable ingredients for concrete and determining their proportions which would produce, as economically as possible, a concrete that satisfies the job requirements. The proportioning of the ingredients of concrete is an important phase of concrete technology as it ensures quality and economy. In pursuit of the goal of obtaining concrete with desired performance characteristics, the selection of component materials is the first step, the next step is a process called mix design by which one arrives at the right combination of the ingredients. There are many methods of designing concrete mixes.

3.3.1 Design of Concrete Mix

The compressive strength of concrete is considered as the index of its quality. Therefore the mix design is generally carried out for a particular compressive strength of concrete with adequate workability so that the fresh concrete can be properly mixed, placed and compacted. The proportions for the mix were calculated adopting the requirements of water as specified in BIS: 10262-1982.

The proportioning of concrete mixes consists of three interrelated steps.

(i) Selection of suitable ingredients-cement, supplementary cementing materials, aggregates water and chemical admixtures.

(ii) Determination of the relative quantities of these materials in order to produce as economically as possible a concrete, that has desired rheological properties i.e. strength and durability.

(iii) Careful quality control of every phase of the concrete making process.

In the present study Mix Design for M20 (Design value at the age of 28 days) and M30 (Design value at the age of 28 days) grade concrete is done according to BIS: 10262-1982.

M20 design mix

Data:

Characteristic strength at 28 days = 20 N/mm^2
Degree of quality control expected at site = Good
Maximum size of aggregate = 12.5mm
Degree of workability desired (C.F.) = 0.9 (Medium)
Type of exposure = Mild, no sulfate attack
Concrete use = Concrete structure
Target mean strength = 30 N/mm^2

Ingredients of M20 concrete mix are given in Table 3.11

Table 3.11: Mix Proportion M20

Unit of Batch	Water(Liters)	Cement(Kg)	F.A(Kg)	C.A.(Kg)
Cubic meter content	195	390	569	1165
Ratio of ingredients	0.5	1	1.45	2.98

M30 design mix

Data:

Characteristic strength at 28 days = 30 N/mm^2
Degree of quality control expected at site = Good
Maximum size of aggregate = 12.5mm
Degree of workability desired (C.F.) = 0.9 (Medium)
Type of exposure = Mild, No sulphate attack
Concrete use = Concrete structure
Target mean strength: = 40 N/mm^2

Ingredients of M30 concrete mix are given in Table 3.12

Table 3.12: Mix Proportion M30

Unit of Batch	**Water(Liters)**	**Cement(Kg)**	**F.A(Kg)**	**C.A.(Kg)**
Cubic meter content	189	450	554	1139
Ratio of ingredients	0.42	1	1.23	2.53

3.3.2 Mix Composition

Initially, two series of control mixes were designed to have 28-day compressive strength of 30 MPa (M20 grade of concrete) and 40 MPa (M30 grade of concrete). The concrete mixes were designed with constant cement, fine aggregate, coarse aggregate and superplasticizer. The fine aggregates were replaced with waste foundry sand varying from 0% to 20% at the equal interval of 5%, to study the effect of replacement of fine aggregates with waste foundry sand on the strength and durability properties of concrete.

Control mix (0%WFS) having 30 MPa strength was designated as M-1 and mixes made with WFS were designated with M-2, M-3, M-4 and M-5. Similarly control mix (0% WFS), having compressive strength 40 MPa was designated as M-6 and mixes with WFS were designated as M-7, M-8, M-9 and M-10. The detailed descriptions of all mixes are given in Table 3.13. The details of mix proportions of M20 and M30 grade of concrete mixes are given in Tables 3.14 and 3.15.

Table 3.13: Detailed Description of Concrete Mixes

M20 Grade of concrete	
M-1	0% WFS
M-2	5% WFS
M-3	10% WFS
M-4	15% WFS
M-5	20% WFS
M30 Grade of concrete	
M-6	0% WFS
M-7	5% WFS
M-8	10% WFS
M-9	15% WFS
M-10	20% WFS

Table 3.14: M20 Grade Mixes

Mixture No.	**M-1**	**M-2**	**M-3**	**M-4**	**M-5**
Cement(Kg/m^3)	390	390	390	390	390
Natural sand (Kg/m^3)	569	541	513	484	456
WFS (%)	0	5	10	15	20
WFS (Kg/m^3)	0	28	56	85	113
Coarse aggregate (12.5mm) (Kg/m^3)	1165	1165	1165	1165	1165
W/C ratio	0.5	0.5	0.5	0.5	0.5
Water (Kg/m^3)	195	195	195	195	195
Super plasticizer(L/m^3)	0.59	0.59	0.59	0.59	0.59
Slump (mm)	90	85	85	80	80
Air temperature (°c)	27	27	28	27	27
Concrete temperature (°c)	26	27	27	26	26

Table 3.15: M30 Grade Mixes

Mixture No.	**M-6**	**M-7**	**M-8**	**M-9**	**M-10**
Cement(Kg/m^3)	450	450	450	450	450
Natural Sand (Kg/m^3)	554	527	500	471	443
WFS (%)	0	5	10	15	20
WFS (Kg/m^3)	0	27	54	83	111
Coarse Aggregate (12.5mm)(Kg/m^3)	1139	1139	1139	1139	1139
W/C ratio	0.42	0.42	0.42	0.42	0.42
Water (Kg/m^3)	189	189	189	189	189
Super Plasticizer(L/m^3)	1.65	1.65	1.65	1.65	1.65
Slump (mm)	90	80	80	80	75
Air Temperature (°c)	27	27	28	27	27
Concrete Temperature (°c)	27	27	26	26	26

3.4 CASTING OF SPECIMENS

All the specimens were cast having mix proportions as given in Tables 3.14 and 3.15. For these mix proportions, required quantities of materials were weighed. The mixing procedure adopted was as follows:

i. The cement and foundry sand were dry mixed in a tray for about 5 minutes. A uniform color was obtained without any clusters of cement, foundry sand.
ii. Weighed quantities of coarse aggregates and sand were then mixed in dry state.
iii. The mix of cement and foundry sand was added to the mix of coarse aggregates and sand and these were mixed thoroughly until a homogeneous mix was obtained.
iv. Water was then added in three stages as given below:
    a. 50% of total water to the dry mix of concrete in first stage.
    b. 40% of water and superplasticizer to the wet mix.
    c. Remaining 10% of water was sprinkled on the above mix and it was thoroughly mixed in the mixer.

All the moulds were properly oiled before casting the specimens. The casting immediately followed mixing, after carrying out the tests for fresh properties. The top surface of the specimens was scraped to remove excess material and achieve smooth finish. The specimens were removed from moulds after 24 hours and cured in water till testing or as per requirement of the test.

3.5 TESTING PROCEDURE

After required period of curing, the specimens were taken out of the curing tank and their surfaces were wiped off. Besides measuring the fresh properties (workability, air content and concrete temperature), following tests were performed on hardened concrete.

3.5.1 Strength Properties

- Compressive strength (BIS: 516 – 1959)
- Splitting tensile strength (BIS: 5816 – 1999)
- Modulus of elasticity (BIS: 516 – 1959)

These properties were determined at the age of 7, 28, 91, and 365 days.

3.5.2 Durability Properties

- Abrasion resistance (BIS: 1237 – 1980)
- Rapid chloride permeability test (ASTM C 1202)
- Deicing salt scaling resistance (ASTM C 672)

The specimen properties were determined at the age of 28, 91, and 365 days.

3.5.3 Non-Destructive Testing

Rebound hammer and Ultrasonic pulse velocity tests were conducted on concrete cubes of both the grades of concrete made with WFS

3.6 FRESH PROPERTIES

The workability of fresh concrete is a composite property which includes the diverse requirements of stability, mobility, compactability, placeability and finishability. There are different methods for measuring the workability. Each of them measures only a particular aspect of it and there is really no unique test which measures workability of concrete in its totality.

The fresh properties were studied in the following tests with the order of testing as mentioned below:

i. Slump test
ii. Compaction factor

For determining the fresh properties, slump flow and Compaction factor tests were performed as envisaged by BIS: 1199-1959. All fresh test measurements were duplicated and the average of measurements was given.

3.6.1 Slump Test

The vertical settlement of unsupported fresh concrete, flowing to the sides and sinking in height is known as slump. Slump is a measure indicating the consistency or workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not show any segregation or bleeding. The setup of the slump test is shown in Fig. 3.2.

Fig. 3.2 Slump Test

3.6.2 Compaction Factor Test

Compaction factor test is based on the definition, that workability is that property of the concrete that determines the amount of work required to produce full compaction. The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction as shown in Fig.3.3.

Fig. 3.3 Compaction Factor

3.7 STRENGTH PROPERTIES

Compressive strength, splitting tensile strength and modulus of elasticity of mixes were determined at various ages as per BIS 516:1959 are given below:

i. Cube Compressive strength at the age of 7, 28, 90 and 365 days.
ii. Splitting Tensile strength of cylinders at the age of 7, 28, 90 and 365 days.
iii. Modulus of Elasticity at the age of 7, 28, 91 and 365 days.

3.7.1 Compressive Strength

Cube specimens of size 150mm were cast for compressive strength as per Indian standard specifications BIS: 516-1959. After casting, all tests specimens were finished with steel trowel. Immediately after finishing, the specimens were covered with sheets to minimize the moisture loss from them. Specimens were demoulded after 24-hours and then cured in water at approximately room temperature till testing. Compressive strength tests for cubes were carried out at 7, 28, 90 and 365 days. All the specimens were tested in an automated CTM shown in Fig. 3.4. The compressive strength was then calculated according to the formula:

$$\sigma = P / A$$

Where σ = Compressive Strength (N/mm^2)

P = Maximum load (N)

A = Cross section area of cube (mm^2)

Fig. 3.4 Compressive Strength Test

3.7.2 Splitting Tensile Strength

The splitting tensile strength is well known indirect test used for determining the tensile strength of concrete. Tensile strength is one of the most important fundamental properties of concrete. An accurate prediction of tensile strength of concrete will help in mitigating cracking problems, improve shear strength prediction and minimize the failure of concrete in tension due to inadequate methods of tensile strength prediction. The splitting tensile strength was determined at the age of 7, 28, 90 and 365 days on cylinders 150 mm x 300 mm as per Indian standard specifications BIS: 516-1959. The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the plates. Due to the applied line loading a fairly uniform tensile stress is introduced over nearly two third of the loaded diameter as obtained from an elastic analysis. The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by

$$\sigma = 2P/\pi dL$$

Where σ = Tensile Stress (N/mm^2)
P = Applied load at failure (N)
d = Diameter of cylinder (mm)
L = Length of cylinder (mm)

The load ‘P’ is applied (as line load) on the cylinder specimen in compression testing machine. At failure load P the specimen fails by splitting along the loaded diameter as shown in Fig. 3.5.

Fig. 3.5 Splitting Tensile Strength

3.7.3 Modulus of Elasticity

The elastic modulus of concrete is very important mechanical parameter reflecting the ability of the concrete to deform elasticity.

The modulus of elasticity or Young's modulus is defined as the slope of the stress strain curve with the proportional limit of a material. For calculating the MOE of concrete, test were conducting on 150 mm x 300 mm cylinder specimens at the age of 7, 28, 91 and 365 days as per Indian standard specifications BIS: 516-1959. Before performing the MOE test, three concrete cube specimens were broken first to determine the compressive strength of the concrete. Compressometer was used for determining the change in length of concrete specimen on compressive loading. The compressometer consist of two frames for clamping to the specimens by means of five tightening screws with a hardened and tapered end. Two spacers hold the two frames in positions. Dial gauge was attached with compressometer. Least count of dial gauge was 0.025mm. Load was applied on specimen in accordance with BIS 516:1959. Rate of loading was 14N/mm^2/min. The cylinders for the modules of elasticity test were loaded and unloaded three times. The data from the first load cycle was disregarded. The average value from the last two cycles was recorded. The MOE then calculated according to the formula.

Fig. 3.6: Modulus of Elasticity

$$\sigma = \frac{P}{A}, \quad A = \frac{\pi}{4} d^2, \varepsilon = \frac{\Delta L}{L}, E = \frac{\sigma}{\varepsilon}$$

Where σ = Compressive stress (N/mm^2)

P = Compressive force (N)

A = Area of cylinder specimen

d = Diameter of cylinder (mm)

ε = Strain

ΔL = Change in length (mm)

L = Length of cylinder (mm)

E = Modulus of elasticity (mm)

3.8 DURABILITY PROPERTIES

For the measurement of durability resistance of mixes, following tests were performed.

i. Abrasion resistance of concrete according to BIS 1237-1980
ii. Scaling resistance of concrete surfaces exposed to deicing chemicals according to ASTM C 672.
iii. Permeability of mixes by Rapid chloride permeability test (RCPT) according to ASTM C 1202.

3.8.1 Abrasion Resistance Test

For abrasion testing, specimens were weighed accurately on a digital balance. After initial drying at room temperature for about 1-2 hours and weighing, the thickness of the specimens was measured at five points (i.e. one at the center and four corners). The grinding path of the disc of the abrasion-testing machine was evenly distributed with 20-gram of abrasive (aluminum) powder. The specimens were fixed in the holding device of the abrasion machine, and a load of 300 N was applied. The grinding machine was then put in motion at a speed of 30 revolutions per minute, and the abrasive powder was continuously fed back in to the grinding path so that it remained uniformly distributed in the track corresponding to the width of the test specimen. The thickness and weight of specimens were taken every 10 minutes interval until the end of the test (60 minutes). The extent of abrasion was determined from the difference in values of thickness measured before and after the abrasion test. Loss in thickness of specimens was also confirmed by the calculation of average loss in thickness of the specimens using the following formula:

$$T = \frac{W_1 - W_2}{W_1} \times \frac{V_1}{A}$$

Where T is average loss in thickness in mm; W_1 is the initial weight of the specimen in gram; W_2 is the mass of the specimen after abrasion in gram; V_1 is the initial volume of the specimens in mm^3; A is the surface area of the specimens in mm^2

3.8.2 Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

The test method (according to ASTM C 672) deals with the determination of the resistance to scaling of a horizontal concrete surface exposed to freezing and thawing cycles in the presence of deicing chemicals. It is intended for the use in evaluating surface resistance qualitatively by visual examination. Specimens of size 225 × 225 × 75 mm were prepared for all mixes. A dike of 25mm wide and 20mm high was placed along the perimeter of the top surface of the specimens. The specimens were removed from the moulds after 24 hours and then cured. Since, the concretes with strength at different ages are to be compared, the specimen were cured till that age. At the desired age, the specimens were removed from moist storage and stored in air for 14 days. After completion of moist and air curing, the flat surface of the specimen was covered with 6mm thick layer solution of calcium chloride solution and water. 100 ml of solution contains 4g of anhydrous calcium chloride. The specimens were placed in freezing environment for 16 to 18 h. The specimens were removed from freezer and placed in air for 6 to 8 h. Water were added at each cycle as necessary to maintain the proper depth of solution. Cycle is repeated after every 24 hours, flushing the surface at the end of each 5 cycles. After making the visual examination, the solution was replaced and the test continued for 50 cycles. Visual rating on the basis of the scaling is given in Table 3.16.

Table 3.16: Rating for Deicing Salt Surface Scaling (ASTM C 672)

Rating	Condition of Surface
0	No scaling
1	Very slight scaling (3mm depth, max., no coarse
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire

3.8.3 Rapid Chloride Permeability Test

A durable concrete is the one that performs satisfactorily under anticipated exposure condition during its service life span. One of the main characteristics influencing the durability of concrete is its permeability to the ingress of chloride. The chloride ion present in the concrete can have harmful affect on concrete as well as on the reinforcement. Swelling of concrete due to chloride ion penetration is 2 to 2.5 times larger than that observed with water penetration. So this test covers the experimental evaluation of electrical conductance of concrete to provide rapid indication of concrete resistance against chloride ion penetration.

The test method (according to ASTM C 1202-97) covered the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. According to Table 3.17 the chloride ion penetrability was decided on the basis of charge passed. The test method consisted of monitoring the amount of electrical current passed through 2-in. (51-mm) thick slices of 4-in. (102-mm) nominal diameter cores or cylinders for a 6-h period. A potential difference of 60 V dc was maintained across the ends of the specimen, one of which was immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, was related to the resistance of the specimen to chloride ion penetration.

Producing, conditioning and testing of the concrete specimen

The cylinders (100mm×200mm) were cast. Specimens were placed in the vacuum desiccator's bowl as shown in Fig 3.7 which illustrates the setup of the vacuum pump, desiccator with stopcock, vacuum gauge and valve and the deaerated water container after the water has filled the desiccators. The vacuum was maintained in the desiccators bowl for 3 hours. The de-aerated water was allowed to flow into the desiccator, so that it completely covers the specimens and no air was allowed to enter. Again the vacuum was maintained for another one hour. Then the specimens were left to soak in the container water for another 18 hours. The specimens were removed from the dessicator, dried and placed in gasket. The liquids (3.0% NaCl and 0.3 N NaOH solutions) were filled in the two cells. Power supply was set to 60V, and initial current reading was recorded. Set up of the apparatus is shown in Fig.3.8. Temperatures of the specimen, applied voltage cell and solutions were maintained at 68 to 77°F (20 to 25°C) at the time the test was initiated (when the power supply was turned on). During the test, the air temperature around the specimens was maintained in the range of 68 to 77°F (20 to 25°C). The values for the current were recorded.

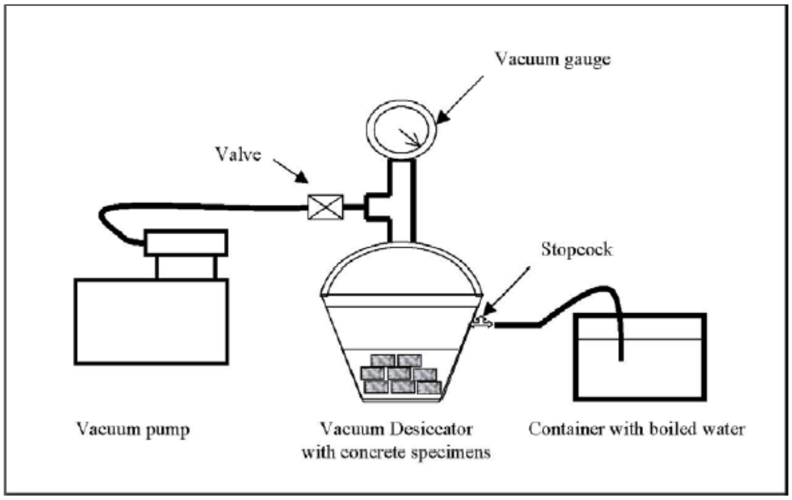


Fig. 3.7: The Vacuum Pump, Desiccator with Specimens and A Container with De-Aerated Water

Fig. 3.8: Rapid Chloride Permeability Test Set Up

Table 3.17: Chloride Ion Penetrability Based on Charge Passed (ASTM 1202-97)

Charge passed (Coulomb)	**Chloride Ion Penetrability**
> 4000	High
2000 – 4000	Moderate
1000- 2000	Low
100 – 1000	Very Low
< 100	Negligible

3.9 NON DESTRUCTIVE TEST

In the non destructive method of testing the Specimen are not loaded to failure. Ultrasonic pulse velocity and Rebound hammer tests were conducted on 150mm concrete cubes as per BIS 13311 (Part 1) and BIS 13311 (part 2) respectively.

3.9.1 Ultra Sonic Pulse Velocity

USPV method consists of measuring the time of travel of an ultrasonic Pulse passing through the concrete to be tested. The Pulse generator Circuit consists of electronic circuit for generating pulse and a transducer for transforming these electronic pulses into mechanical energy having vibration frequency in the range of 20 to 150 KHz. The time of travel between initial on set and the reception of the pulse is measured electronically. The path length between transducer divided by the time of travel gives the average velocity of wave propagation

Battery operated fully portable digitized unit PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) was used shown in Fig. 3.9. The Direct transmission way was used for measuring pulse velocity through concrete.

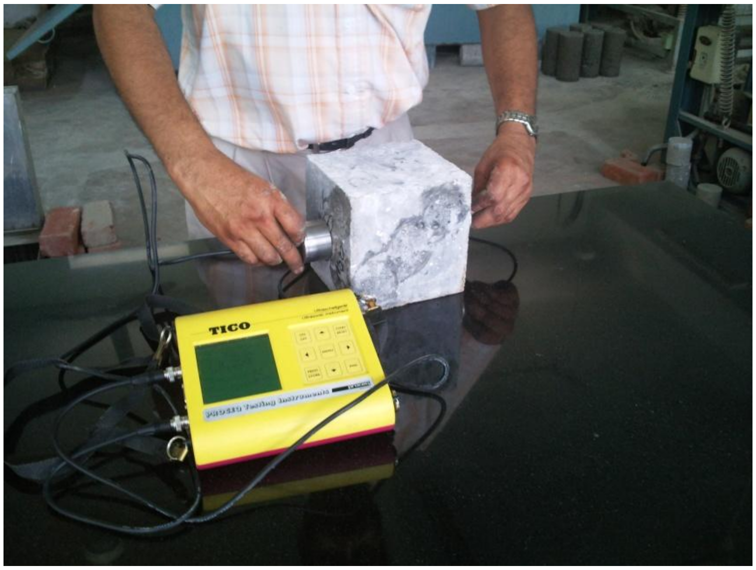


Fig. 3.9: Ultrasonic Pulse Velocity Test

This method was used to check the quality of concrete in terms of density homogeneity and uniformity of concrete. The quality grades of concrete are given in Table 3.18.

Table 3.18: Velocity Criterion for Concrete Quality Grading

Pulse velocity m/sec	**Concrete Quality Grading**
Above 4500	Excellent
3500 – 4500	Good
3000 – 3500	Medium
Less than 3000	Doubtful

3.9.2 Rebound Hammer

Rebound hammer test is also called surface hardness method. The rebound hammer test measure the elastic rebound of concrete and primarily for compressive integration. The test was conducted on 150mm cube at the age of 28, 91 and 365 days. SCHMIDT rebound hammer (digital) was used for testing as shown in Fig. 3.10. In this method a test hammer hits the concrete at a definite energy 2.2Nm and compressive strength is directly obtained from rebound hammer. The equipment was operated vertically downward. The plunger was pressed strongly and steadily against the concrete surface to be tested at right angle. Normally grid was used to locate impact points not less than 20mm apart from each other. BIS 13311(part 2) recommended 12 reading taken over an area mean of compressive strength values was calculated.

Fig. 3.10 Rebound Hammer Test

According to BIS 13311 (part 2), the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in structure is ± 25 percent.

3.10 X-RAY POWDER DIFFRACTOMETRY (XRD)

X-ray powder diffraction technique is the most prominent technique used for unraveling the structure of the materials in bulk and thin film forms. X-ray diffraction is a non-destructive technique used to determine the elements present in any particular substance. X-ray diffraction is based on the fact that, in a mixture, the measured intensity of a diffraction peak is directly proportional to the content of the substance producing it. The samples for X-Ray diffraction analysis were prepared in powdered form. The concrete sample was taken from the inner core of the matrix.

X-ray diffraction analysis (XRD) was done on Philips PW 3071. Diffractometer operated at 45 KV, 40mA with CuKα radiation (λ = 1.54060 A^{o}) has been used shown in Fig. 3.11

Procedure for Deduction of Minerals

(i) For a given sample, XRD graphs are obtained with intensities on Y-axis and 2θ on X-axis.

(ii) Match the d values and intensities of peaks of respective minerals with the fundamental peaks of X-ray powder diffraction files given in the software.

(iii) For any mineral to be present, all the strong peaks should be present in the XRD graph, else the mineral is not present.

Fig.3.11 X-ray Powder Diffractometer

3.11 SUMMARY

In this chapter various properties (specific gravity, fineness modulus, moisture content etc.) of the materials (cement, fine aggregate course aggregate and waste foundry sand) that are used in present work, are presented. Ingredients of M20 and M30 Grades of concrete mixes were determined in accordance with Indian standard code. After this specimens were made and tested for various strength and durability properties of both the grades of concrete mixes.

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

In this chapter, the findings of experimental investigations are presented. In which, various tests were conducted to evaluate the effect of waste foundry sand on compressive strength, splitting tensile strength, modulus of elasticity, abrasion resistance, rapid chloride penetration resistance and deicing salt surface scaling resistance of concrete. In non destructive testing, rebound hammer was used to determine the compressive strength and to check the quality of concrete, ultrasonic pulse velocity test was conducted. Waste foundry sand was used as a partial replacement of fine aggregate at the percentage of 0, 5, 10, 15 and 20%. Design of different concrete mix and procedure of various tests are described in chapter 3.

4.2 COMPRESSIVE STRENGTH

4.2.1 Compressive Strength of M20 Grade (30 MPa) Concrete

Effect of WFS on compressive strength

Effect of WFS on compressive strength of M20 Grade concrete mixes M-1(0% WFS), M-2 (5% WFS), M-3(10% WFS), M-4 (15% WFS) and M-5(20% WFS) at the age of 7, 28, 91 and 365 days are shown in Fig. 4.1.

Mix proportion of control concrete mix M-1 (0% WFS) was 390 kg cement, 569 kg fine aggregate and 1165 kg coarse aggregate per cubic meter of concrete with water-cement ratio 0.5. Compressive strength of control concrete mix was 30 MPa at the age of 28 days. It was found that, at the age of 7 days, compressive strength of mix M1 (0% WFS) was 19.7 MPa and mixes M-2 (5% WFS), M-3 (10%WFS), M-4 (15% WFS) and M-5 (20% WFS) were 22.4, 23.3, 25.3 and 24.8 MPa, respectively. Maximum compressive strength (25.3 MPa) was observed for M-4 (15% WFS) concrete mix; it was 28.42 % more than the control mix M-1(0% WFS). At the age of 28 days, percentage increase in compressive strength was 14.6, 22.6, 26 and 23.3% for mixes

M-2, M-3, M-4 and M-5 than control mix M-1(30MPa). At 91 days, concrete mixes M-2, M-3, M-4 and M-5 exhibited increase in compressive strength 11.69, 18.8, 20.8 and 18.2% respectively than M-1 (34.5 MPa). Similarly, at the age of 365 days, there was 9.45, 17.82, 21.6 and 18.9 % increase in compressive strength for concrete mixes M-2, M-3, M-4 and M-5 in comparison to control M-1 (37 MPa). In investigation, it was observed that compressive strength of concrete increased with the increase in WFS content up to 15% as partial replacement of sand.

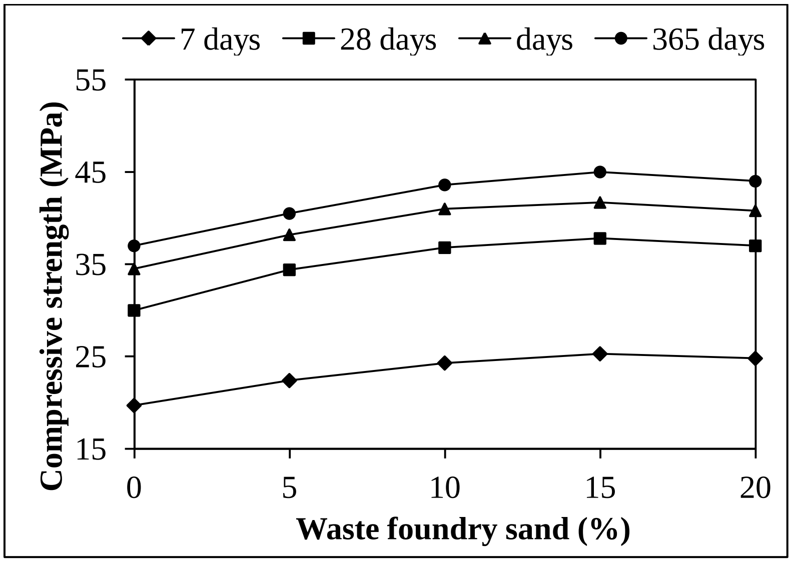


Fig 4.1: Compressive Strength verses Waste Foundry sand

Effect of age on compressive strength

Effect of age on compressive strength of M20 Grade (30 MPa) concrete mixes are shown in Fig. 4.2. Compressive strength of all concrete mixes increased with age. Concrete mix M-1 (0% WFS) achieved an increase of 52.3, 75.48 and 88.23 % at the age of 28, 91 and 365 days respectively, when compared with 7 days compressive strength (19.7 MPa). For mix M-2 (22.4 MPa), compressive strength was increased by 54, 71.1 and 81.45% at the age of 28, 91 and 365 days respectively, whereas an increase of 51.4% was observed at 28 days, 65.6% at 91 days and 78.7% at 365 days for M-3 (10% WFS). When M-4 (15% WFS) was compared with 7 days compressive strength (25.3 MPa), it was found that it increased by 50, 65.6 and 78.8%.

Similarly, increase in compressive strength for mix M-5(20% WFS) was 50, 65.4 and 78.7% at the age of 28, 91 and 365 days, respectively than 7 days compressive strength (24.8 MPa).

Comparative study of compressive strength between 7 to 28 days indicate that % increase in compressive strength was observed as 52.3, 54, 51.4, 50.1 and 50% for mix M-1, M-2, M-3, M-4 and M-5 respectively. Concrete mix M-1, M-2, M-3, M-4 and M-5 exhibited increase in compressive strength by 15, 11.1, 11.4, 10.3 and 10.2% when comparative study was done between 28 and 91 days, whereas % increased was 7.3% for M-1, 6.1% for M-2, 6.3% for M-3, 7.9 % for M-4 and 7.8% for concrete mix M-5 between 91 to 365 days.

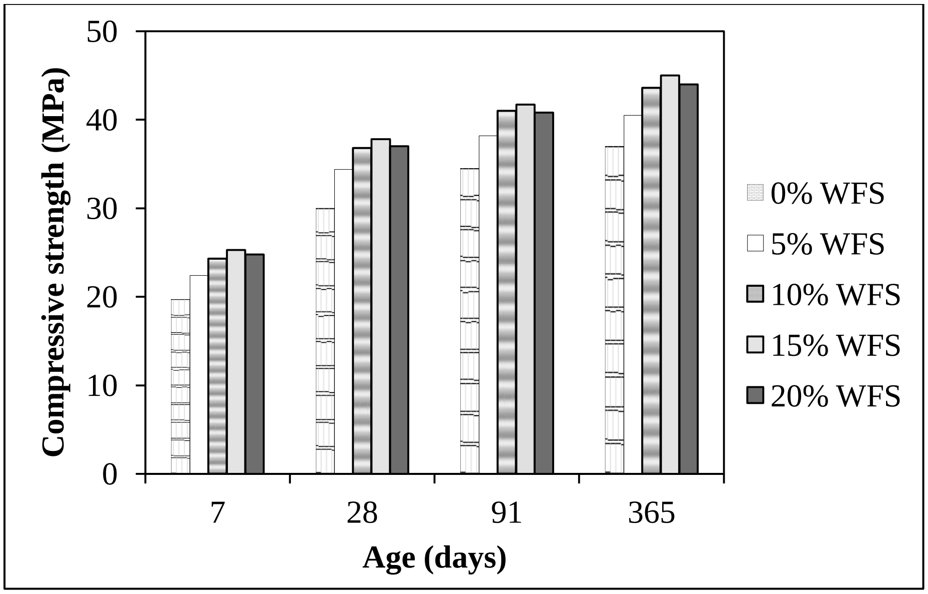


Fig 4.2: Compressive Strength verses Age

Comparative study of compressive strength between all ages indicated that % increase in compressive strength decreased with the increase in WFS content for all mixes. It decreased by 54% to 50% in 7 to 28 days, 15 % to 10.2% in 28 to 91 days and 7.9 to 6.1 in 91 to 365 days. 4% and 4.8% decrease was observed when comparative study was done between 7 to 28 days and 28 to 91 days respectively. It was studied during 91 to 365 days, there was very less % reduction i.e. 1.8% in compressive strength.

4.2.2 Compressive Strength of M30 Grade (40 MPa) Concrete

Effect of WFS on compressive strength

Effect of WFS on concrete mixes M-6 (0% WFS), M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS) and M-10 (20% WFS) are shown in Fig. 4.3. Mix proportion of control concrete mix M-6 (0% WFS) was 450 kg cement, 554 kg fine aggregate and 1139 kg coarse aggregate per cubic meter of concrete with water cement ratio 0.42. Compressive strength of control concrete mix M-6, without waste foundry sand, was 40 MPa at the age of 28 days.

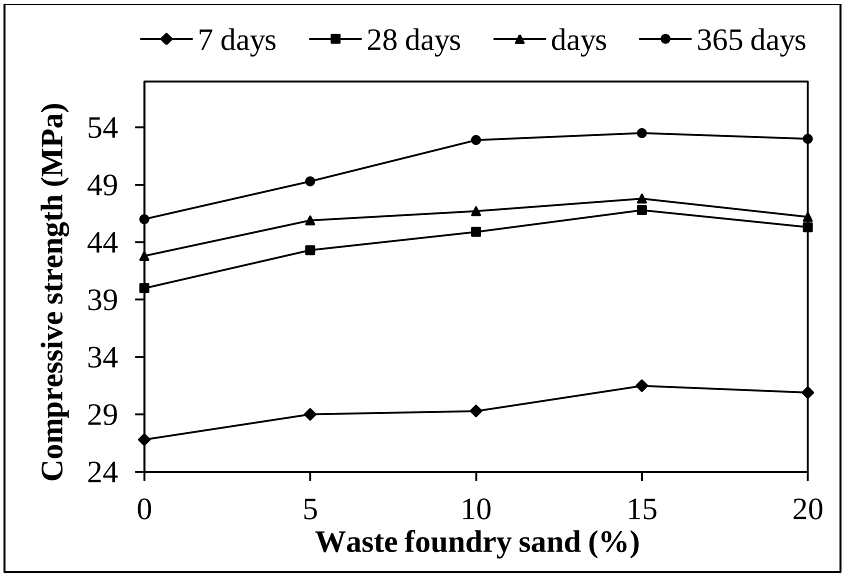


Fig. 4.3: Compressive Strength Verses Waste Foundry Sand

It was observed that concrete mixes made with WFS exhibited higher compressive strength than control concrete. Compressive strength of control mixture M-6 (0% WFS) was 26.8 MPa at 7 days. From these results, it was found that 7 days compressive strength increased by 8.2%, 9.3%, 17.4% and 15.17% for mixtures M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS) and M-10 (20% WFS), respectively than control mix M-6 (0% WFS). At 28 days, increase in strength was 8.25%, 12.25%, 17% and 13.25% for M-7, M-8, M-9 and M-10 mixes, when compared with M-6 (40 MPa) respectively. Percentage increase in compressive strength observed for mixes M-7, M-8, M-9 and M-10 were 7.44, 9.36, 12 and 8.2% respectively than mix M-6 (42.8MPa) at the age of 91 days. At 365 days, concrete mixes (M-7, M-8, M-9 and M-10) achieved an increase of compressive strength 7.26, 15.2, 16.5 and 15.4 % when compared with compressive strength 46MPa for mix M-6.

Effect of age on compressive strength

Effect of age on compressive strength of M30 grade concrete is shown in Fig. 4.4. It is evident that compressive strength of concrete mixes increased with age At the age of 7 days, compressive strength of concrete mix M-6 (0% WFS) was 26.8 MPa. It increased by 48.8, 59.2 and 71.1% at 28, 91 and 365 days, respectively. At 7 days, mix M-7 (5% WFS) exhibited compressive strength of 29 MPa. There was an increase of 50.1% at 28 days, 59.2% at 91 days and 71.1% at 365 days. Percentage increase in strength of mix M-8(10% WFS) was 53.1, 59.2 and 80.3% at 28, 91 and 365 days respectively when compared with 7 days compressive strength of mix M-8 (29.3 MPa). Concrete mix M-9(15% WFS) achieved an increase of 49, 52.2 and 70.4% strength at the age of 28, 91 and 365 days respectively than 7 days strength (31.5 MPa). Similarly, compressive strength of mix M-10(20% WFS) was 30.9 MPa at 7 days. It was increased by 48% (28 days), 50.5% (91 days) and 73 %(365 days).

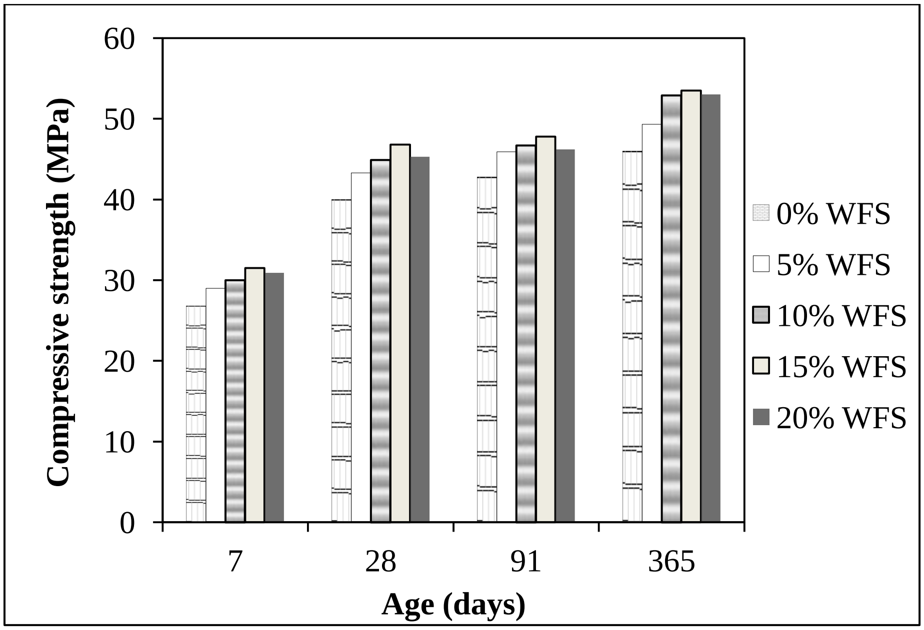


Fig. 4.4: Compressive Strength versus Age

In this paragraph, comparative study is done between the ages. Mix M-6 (0% WFS), M-7 (5% WFS), M-8 (10%WFS), M-9 (15% WFS) and M-10 (20% EFS) achieved an increase of 48.84%, 50.1, 53.1, 49 and 48% in compressive strength, respectively when study was done between 7 to 28 days. With the increase in age from 28 to 91 days, % increase in compressive strength of mixes M-6, M-7, M-8, M-9 and M-10 were 7%, 6%, 4%, 2.13% and 1.98%. Comparative study of compressive strength between 28 and 91 days indicate that % increase in compressive strength decreases with the increase in WFS content at 91 days in compression to 28 days, it was decreased by 7% to 1.98%. Similarly % increased was observed 7.5% for M-6, 7.4% for M-7, 13.3% for M-8, 11.9 % for M-9 and 14.7% for concrete mix M-10 between 91 to 365 days.

In present investigation, compressive strength of concrete increased with the increase in WFS content up to 15% as partial replacement of sand shown in Fig. 4.1 and 4.3 for both grade of concrete (M20 and M30). This could be due to dense matrix because WFS is fine sand and its particle size varies between 600µ to 150µ. Reduction in compressive strength with the inclusion of 20% WFS could probably due to increase in surface area of fine particles led to the reduction the water cement gel in matrix, hence; binding process of coarse and fine aggregate does not take place properly.

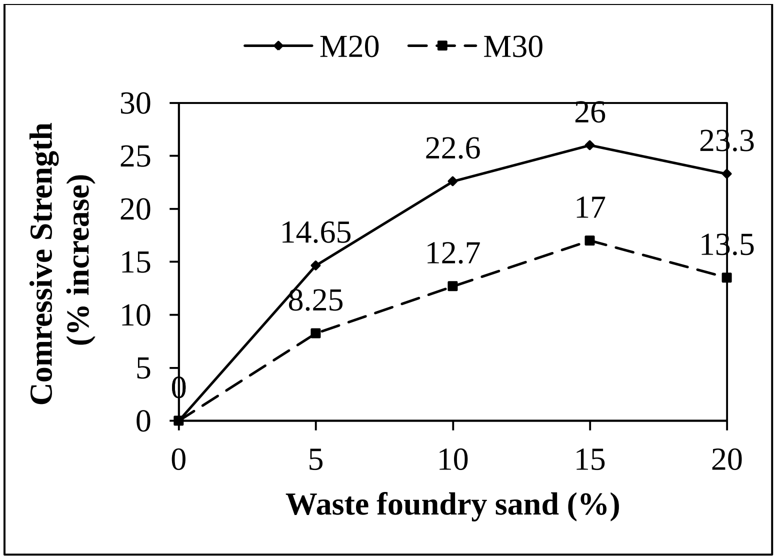
Similar results were reported by Guney et al.(2010), Etxeberria et al. (2010) and Siddique et al.(2009) in their investigation. Guney et al. (2010) reported that the concrete with 10% WFS showed almost similar strength. It may indicate that the particle size distribution of the mixture with 10% waste foundry sand has sufficient adherence than the other mixtures with waste foundry sand. Etxeberria et al. (2010) reported that concrete made with green foundry sand and chemical foundry sand obtained higher compressive strength than conventional concrete when the concrete is produced with high water-cement ratio. Siddique et al. (2009) reported that there was marginal increase in the compressive strength of concrete mixtures with the inclusion of foundry sand as partial replacement of regular sand. With increase in WFS percentage, compressive strength increased by 8% to 19% and modulus of elasticity varied between 5.2 to 12% depending upon foundry sand content and age of testing.

4.2.3 Comparison between M20 and M30 Grade of Concrete

Comparison between M20 and M30 Grade of concrete was evaluated on the basis of percentage increase. Percentage increase in compressive strength for all mixes of M20 and M30 Grades of concrete was calculated in comparison with 28-day compressive strength of mix M-1(0%WFS) for M20 Grade of concrete and 28 days compressive strength of mix M-6(0%WFS) for M30 Grade of concrete. Percentage increased value are shown in Fig 4.5. It can be seen from these figures that there was more percentage increase in compressive strength for M20 Grade of concrete than M30 Grade of concrete. Maximum percentage increase was found at 15% replacement at all age. At 15% replacement of fine sand with WFS, M20 Grade of concrete showed better percentage increase than M30 Grade of concrete by 9% at 28 days, 19.5% at 91 days and 16.2% at 365 days.

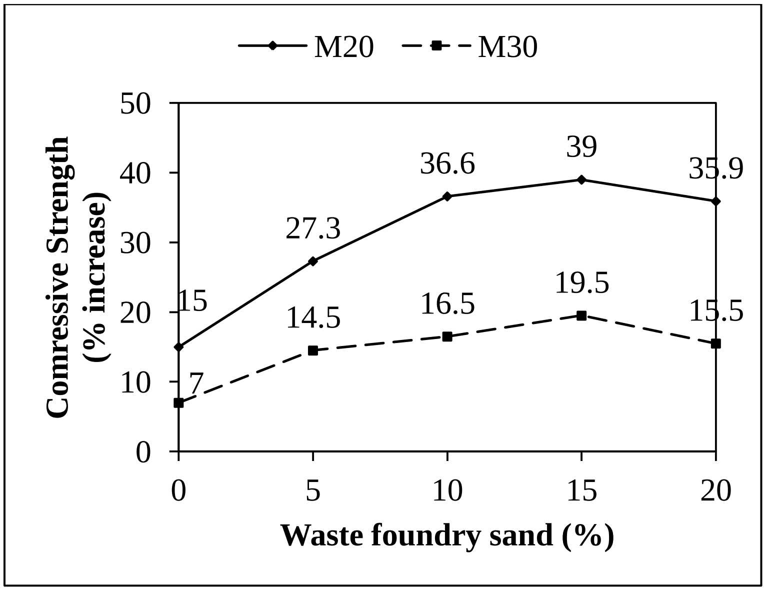
It means that effect of WFS is more upon M20 Grade of concrete than M30 Grade of concrete. It is probably due to the packing behavior of matrix particle. M20 Grade of concrete has more voids between the particles than M30 Grade of concrete so voids of M20 Grade of concrete is well packed by fine particles of WFS.

(28days)



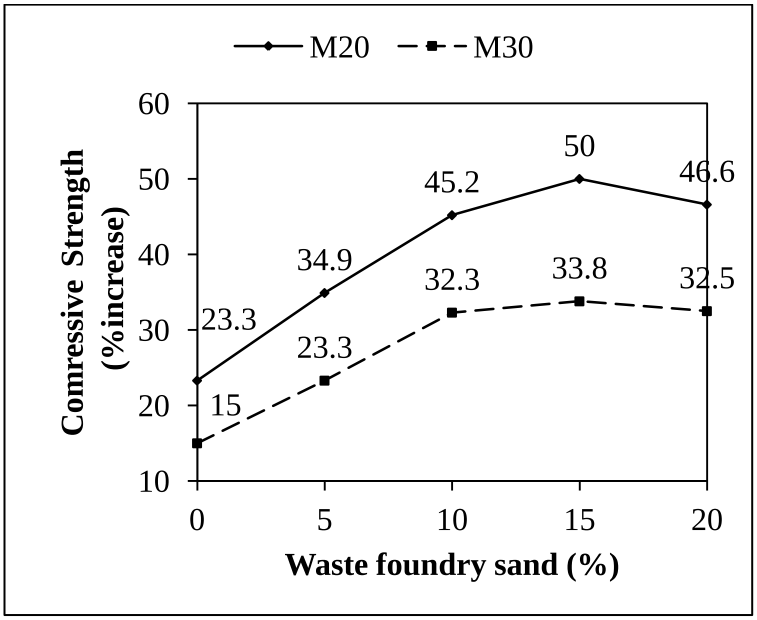
(a)

(91days)



(b)

(365 days)



(c)

Fig. 4.5: Compressive Strength verses WFS at 28, 91 and 365 Days.

4.3 SPLITTING TENSILE STRENGTH

4.3.1 Splitting Tensile Strength for M20 Grade (30MPa) Concrete

Effect of WFS on splitting tensile strength

Effect of WFS on splitting tensile strength of concrete mixes is shown in Fig. 4.6.

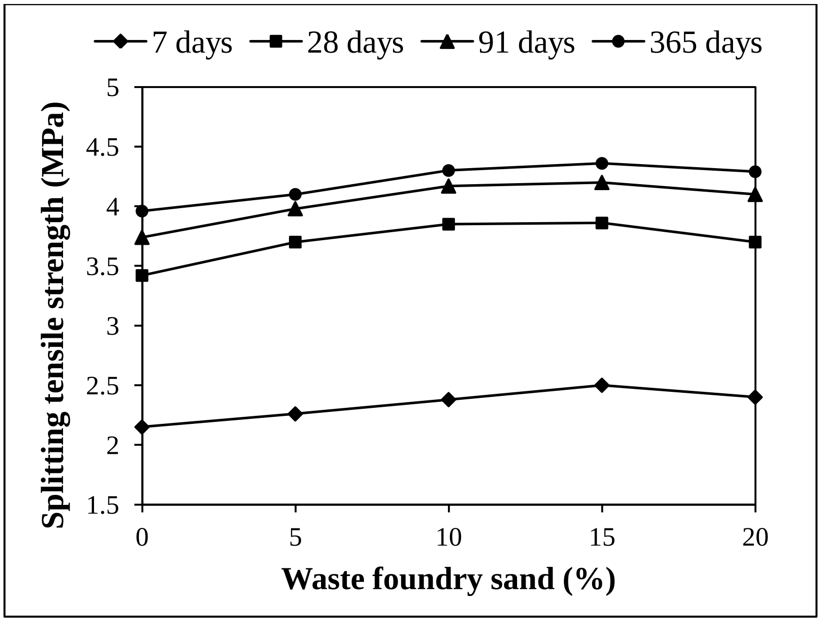


Fig. 4.6: Splitting Tensile Strength verses Waste Foundry Sand

The variations in splitting tensile strength with waste foundry sand content were similar to that observed in case of compressive strength. Splitting tensile strength of concrete mixes increased with the increase in WFS content. Splitting tensile strength of control mix M-1(0% WFS) was 2.15 MPa at 7 days. It increased by 5.1%, 10.7%, 16.3% and 11.6% for M-2 (5% WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS) respectively. Higher value of splitting tensile strength was observed at 15% WFS. At the age of 28 days, increase was 8.2%, 12.5%, 12.8% and 8.2% for M-2, M-3, M-4 and M-5 concrete mixes respectively than mix M-1 (4.23MPa). At 91 days, splitting tensile strength of mix M-1(0% WFS) was 4.31 MPa. Concrete mix M-2, M-3, M-4 and M-5 achieved an increase of 6.4, 11.48, 12.3 and 9.6%.. At 365 days, percentage increase in splitting tensile for mixes M-2, M-3, M-4 and M-5 were 3.5, 8.6, 10.1 and 8.3% than that of mix M-1 (3.96MPa). It was observed that up to 15% replacement of natural sand with WFS, concrete mixture M-4 (15% WFS) showed higher value of splitting tensile strength among all mixes.

Effect of age on splitting tensile strength

Effect of age on splitting tensile strength of M20 Grade concrete mixes are shown in Fig. 4.7. Splitting tensile strength of all concrete mixes increased with age.

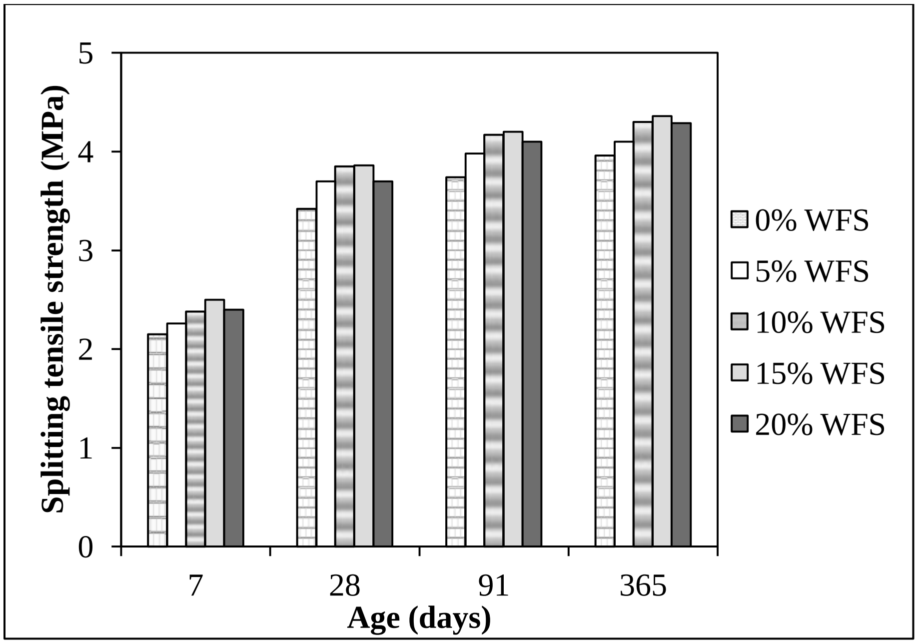


Fig. 4.7: **Splitting Tensile Strength versus Age**

Concrete mix M-1 (0% WFS) achieved an increase of 59.1, 73.9 and 84.2% at the age of 28, 91 and 365 days respectively, when compared with 7 days splitting tensile strength (2.15 MPa). For mix M-2 (2.26 MPa), splitting tensile strength was increased by 63.6, 76.1 and 81.3% at 28, 91 and 365 days, respectively, whereas an increase of 61.7% was observed at 28 days, 75.21% at 91 days and 80.6% at 365 days for M-3 (10% WFS). When M-4 (15% WFS) was compared with 7 days splitting tensile strength (2.5MPa), it was found that it increased by 54.4, 70.2 and 78.9%.

Similarly, increase in splitting tensile strength for mix M-5(20% WFS) was 54.2, 70.9 and 78.9% at the age of 28, 91 and 365 days respectively than 7 days splitting tensile strength (2.4 MPa).

The concrete mixes M-1, M-2, M-3, M-4 and M-5 showed an increase in splitting tensile strength between 28 to 91 days, by 9.4, 7.6, 9.1, 8.1 and 10.8% respectively. Similar trend are observed in between 91 to 365 days (Fig 4.6). Splitting tensile strength of all mixes are continue to increase with increase in age. It was increased by 5.95% for mix M-1(0% WFS), 3.1% for mix M-2 (5% WFS), 2.45% for mix M-3 (10% WFS) and 4.6% for mixes M-4 (15% WFS) and M-5 (20% WFS).

4.3.2 Splitting Tensile Strength for M30 Grade (40MPa) Concrete

Effect of WFS on splitting tensile strength

Influence of WFS as partial replacement of fine aggregate (sand) is shown in Fig. 4.8.

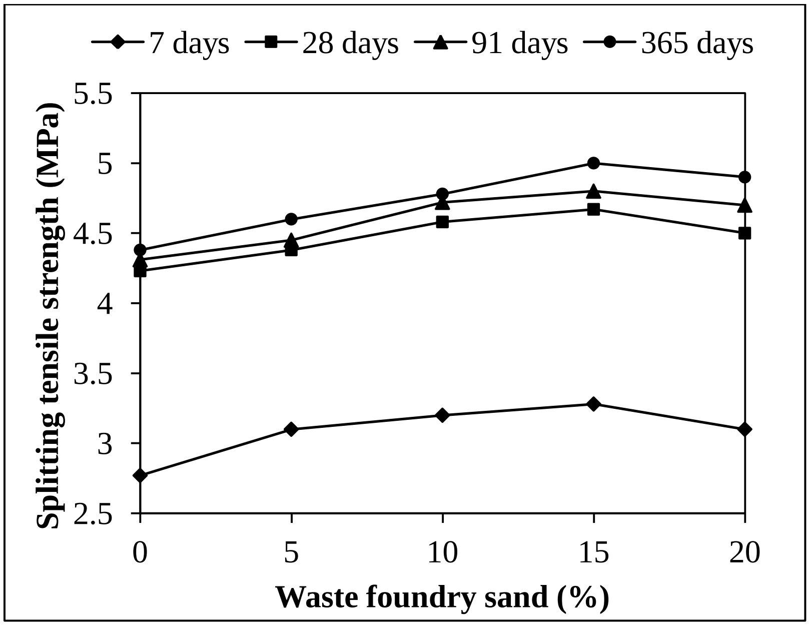


Fig. 4.8: Splitting Tensile Strength verses Waste Foundry Sand

The variation in the splitting tensile strength with waste foundry sand (WFS) was similar to that observed in case of splitting tensile strength (M20 Grade concrete). Splitting tensile strength of concrete mixes increased with the increase in WFS content. At the age of 7 days, it increased by 11.91, 15.5, 18.4, and 11.9% for mixes M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS), and M-10 (20% WFS) when compared with 7 days strength (2.77 MPa). At 28 days, splitting tensile strength of mixes M-7, M-8, M-9 and M-10 showed increase of 3.54, 8.26, 10.4 and 6.4% respectively in comparison with the strength (4.23 MPa) of mix M-6 (0% WFS). At the age of 90 days, there was an increase of 3.3, 9.5, 11.4 and 9.1% for M-7, M-8, M-9 and M-10 was observed, when compared to 91 days strength (4.31MPa) of mix M-6. Similar trend was observed at 365 days. Strength was increased due to increase of WFS content in concrete mixes. Concrete mixes achieved in percentage increase of splitting tensile strength of 5.1, 9.1, 14.1 and 11.8% for M-7, M-8, M-9 and M-10 respectively.

From Fig. 4.8, it can be seen that, the strength variation for the various percentage of replacement of fine aggregate was observed to be linearly increasing from 0% to 15%. Mix M-9 (15% WFS) attained higher splitting tensile strength among all mix at all age. At 20 % replacement of fine aggregate with WFS, it goes to decreasing. This trend was observed in all mixes at all age. It could be probably due to the increasing of fine particle of waste foundry sand in concrete mixes and led to decreasing the water cement gel.

Effect of age on splitting tensile strength

Effect of age on splitting tensile strength of concrete mixes made with and without waste foundry sand is shown in Fig 4.9. Mix M-6 (0% WFS) achieved splitting tensile strength 2.77 MPa at 7 days. It increased by 52.7, 55.6 and 58.2% at 28, 91 and 365 days respectively. At 7 days, strength of mix M-7(5% WFS) was 3.10 MPa, and it attained a strength of 4.38, 4.45 and 4.60 MPa at the age of 28, 91 and 365 days; percentage increase of 41.4, 43.6 and 48.5% when compared with 7 days strength. Mix M-8 (10% WFS) achieved splitting tensile strength of 3.2 MPa at 7 days, 4.48 MPa at 28 days, 4.72 MPa at 91 days and 4.78 MPa at 365 days. Maximum increase was observed 4.78 MPa at 365 days. Similar trend was observed for mix M-9(15% WFS) and for mix (20% WFS). Mixes M-9 and M-10 achieved strength 5 MPa and 4.9 MPa at 365 days. It increased by 52.4% and 58.1 % in comparison with 7 days strength 3.28 MPa and 3.10 Mpa respectively

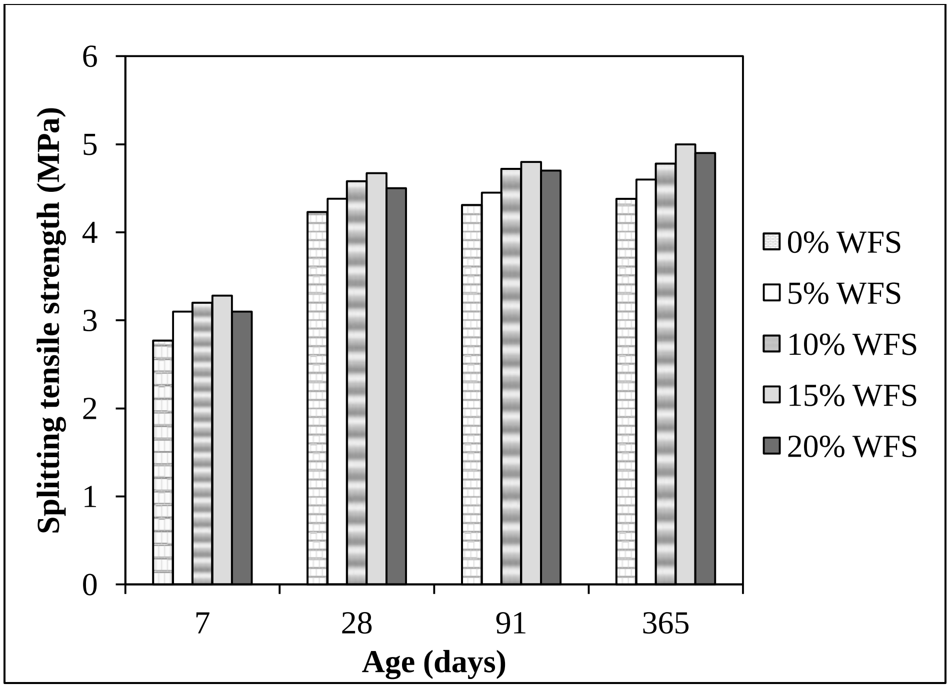


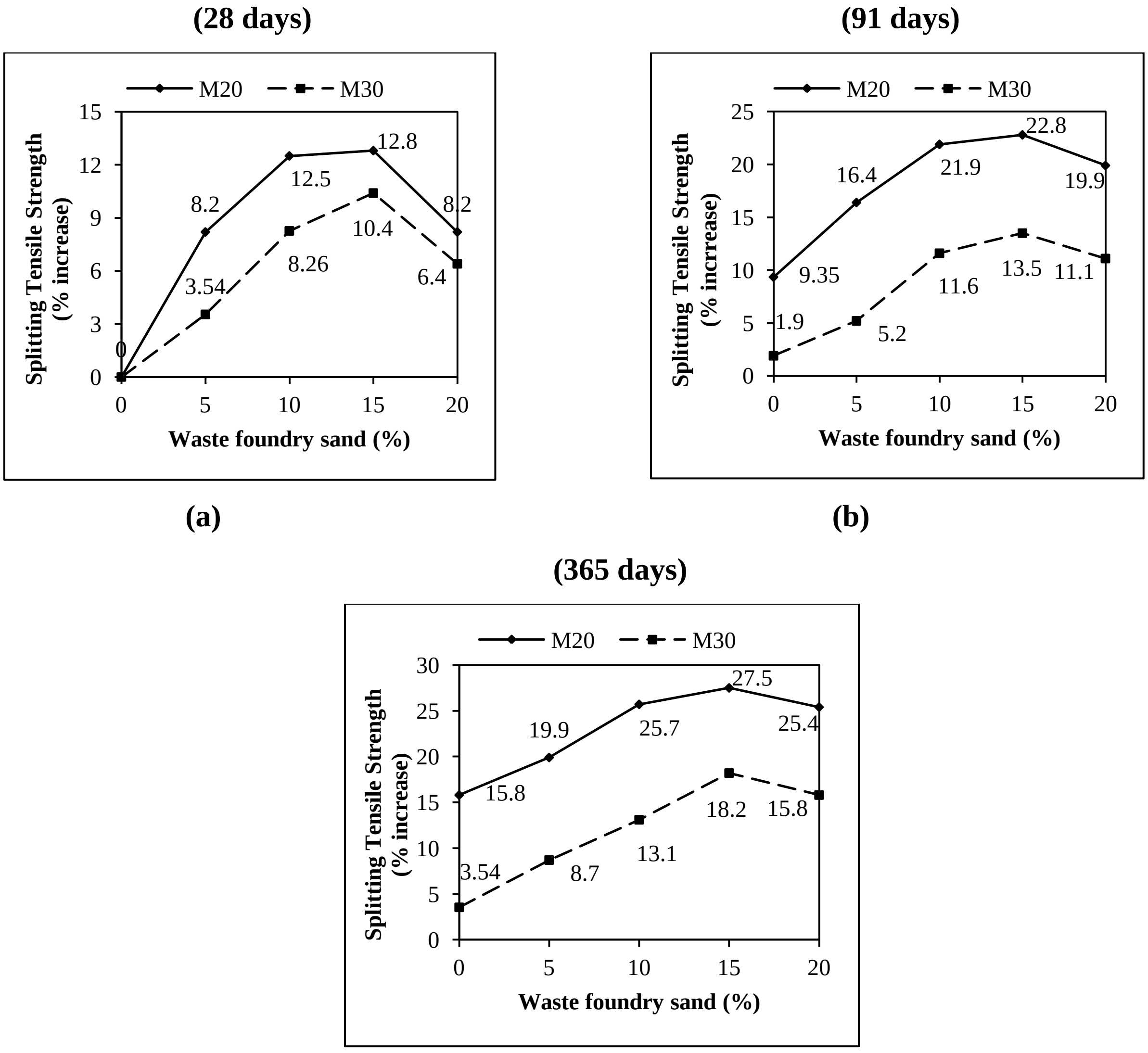
Fig. 4.9: **Splitting Tensile Strength versus Age**

Similar results were reported by Etxeberria et al. (2010) that splitting tensile strength increased with inclusion of WFS in concrete when concrete made with higher water cement ratio. Siddique et al. (2009) have also reported on splitting tensile strength. They observed that splitting-tensile strength of concrete mixtures increased with the increase in foundry sand content and age of curing. It increased from 3.6% to 9% at 28 day of curing and from 6.5% to 9.3% at 56 day of curing Guney et al. (2010) has reported that splitting tensile strength value was higher at 10% replacement of natural sand with WFS than control mixture. According to Gunny et al. splitting tensile strength values can be acceptable when compared to ACI 318 relationship.

4.3.3 Comparison between M20 and M30 Grade of Concrete

Comparison between splitting tensile strength of M20 and M30 grades of concrete was calculated in term of percentage increase. Percentage increase of splitting tensile strength of both grade of concrete mixes at the age of 28, 91 and 365 days are shown in Fig. 4.10. M20 Grade of concrete mixes (M-1 to M-5) showed higher percentage increase in splitting tensile strength than M30 Grade of concrete mixes (M-6 to M-10). Percentage increase was determined in comparison with the 28-day splitting tensile strength of M-1(0% WFS) and M-6(0% WFS) for M20 and M30

Grade of concrete respectively. Maximum increase was found at 15% replacement at all age. At 15% replacement, M20 Grade of concrete mix (M-4) achieved higher percentage increase by 2.4% at 28 days, 9.3% at 91 and 365 days than M30 Grade mix (M-9). It means that, particle size distribution of M20 Grade of concrete mixes with 15% WFS has more adherence than M30 Grade concrete mixes.



(a)

(b)

(c)

Fig. 4.10: Splitting tensile strength verses WFS at 28, 91 and 365 Days

4.4 MODULUS OF ELASTICITY

4.4.1 Modulus of Elasticity of M20 Grade (30MPa) Concrete

Effect of WFS on modulus of elasticity

Effect of WFS on modulus of elasticity of concrete at the age of 7, 28, 91 and 365 days are shown in Fig. 3.11. At 7 days, modulus of elasticity of mix M-1(0%WFS) was 20.5GPa; with increase in WFS content in concrete, modulus of elasticity of mixes M-2 (5% WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS) were 21.1, 21.3, 21.9 and 21.5 GPa respectively.

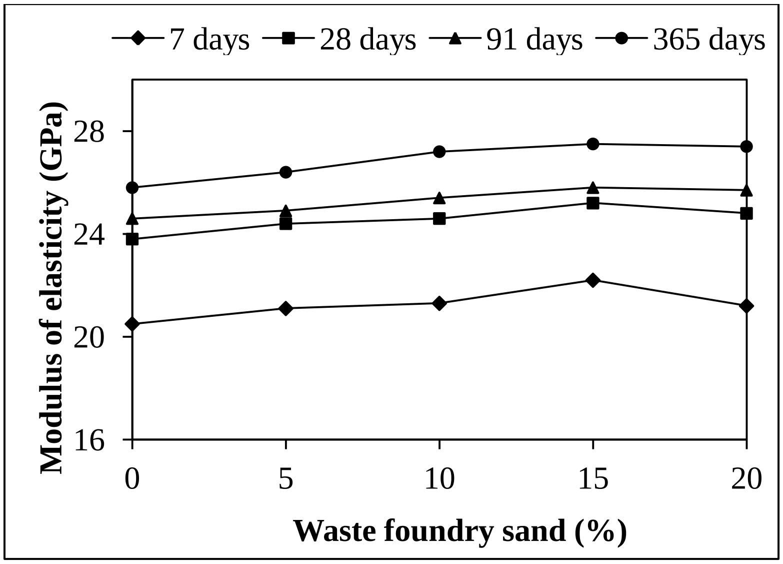


Fig. 4.11: Modulus of Elasticity verses Waste Foundry sand

At 28 days, modulus of elasticity of mix M-1(0%WFS) was 23.8GPa. It increased to 25.2 GPa with 15% WFS; 5.9% increase was observed for mix M-4(15%WFS) when compared with M-1(0%WFS). Similar gain in modulus of elasticity was observed at the age of 91 days. Modulus of elasticity of mix M-1 was 24.6 GPa. Mix M-2, M-3, M-4 and M-5 showed higher values of modulus of elasticity than M-1. It was 24.9, 25.4, 25.8 and 25.7 GPa. Similarly, at the age of 365 days, concrete mixes M-2, M-3, M-4 and M-5 achieved modulus of elasticity of 26.4, 27.2, 27.5 and 25.7 GPa, respectively; 6.6% increase was observed for mix M-4(15% WFS) as compared with control one (25.8 GPa). In investigation, it was observed that modulus of elasticity of concrete increased with the increase in WFS content up to 15% as partial replacement of sand.

Effect of age on modulus of elasticity

Effect of age on modulus of elasticity is shown in Fig. 3.12. It is evident that, inclusion of WFS in concrete mixtures led to increase in modulus of elasticity at all ages.

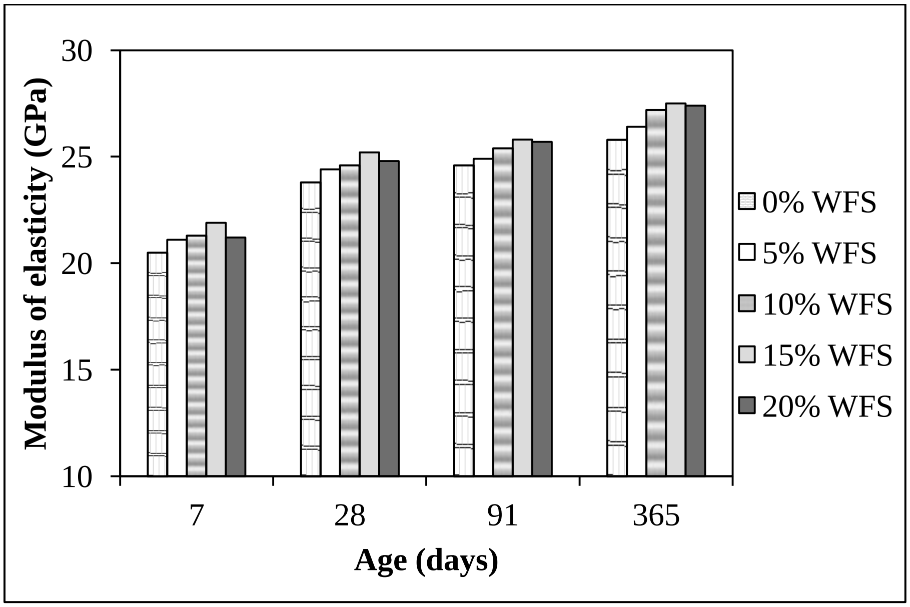


Fig. 4.12: Modulus of Elasticity verses Age

Modulus of elasticity of mix M-1(0%WFS) increased by 16.2, 20.1 and 25.95% at the age of 28, 91 and 365 days, respectively when compared with 7-day modulus of elasticity (20.5GPa). Whereas an increase of 15.5% was observed at 28 days, 17.7% at 91 days and 24.9% at 365 days for M-3(10%WFS). Concrete mix M-3(10% WFS) achieved an increase of 15.5, 17.9 and 24.9% at the age of 28, 91 and 365 days, respectively when compared with 7-day result (21.3GPa). When mix M-4 (15% WFS) was compared with 7 days modulus of elasticity (21.9GPa), it was observed that it increased by 15.2, 17.9 and 25.75%. Similarly, percentage increase found for mix M-5(20% WFS) was 15.3% at 28 days, 19.7 at 91 days and 27.7% at 365 days than 7 days modulus of elasticity (21.5GPa).

It can be seen in Fig 4.11 that, variation in modulus of elasticity was observed linearly increasing up to 15% WFS content. Higher value of modulus of elasticity was observed for mix M-4(15%WFS). At 20 % replacement of fine aggregate with WFS, it starts decreasing. This trend was observed in all mixes at all age. It could be probably due to the packing behavior between the particles. After 15% replacement, no more fine particles required for filling the voids between the particles.

4.4.2 Modulus of Elasticity of M30 Grade (40MPa) Concrete

Effect of WFS on modulus of elasticity

Results of modulus of elasticity of concrete containing WFS at the ages of 7, 28 91 and 365 days is shown in Fig. 4.13. It is evident that, inclusion of WFS in concrete mixtures led to increase in modulus of elasticity.

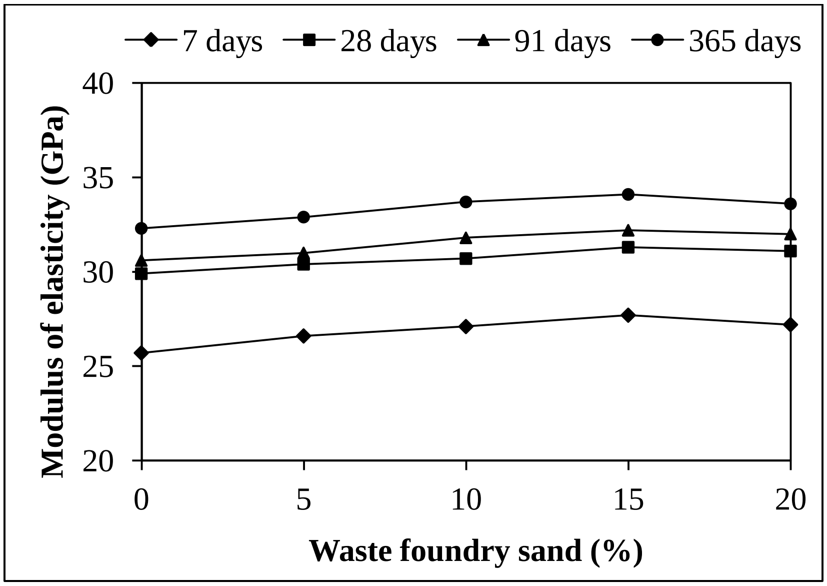


Fig. 4.13: Modulus of Elasticity verses Waste Foundry sand

Modulus of elasticity for mix M-6(0%WFS) at 7 days was 25.7 GPa. At same age with increasing WFS content in concrete, it increased by 3.5, 5.4, 7.7 and 5.8% for mixes M-7(5%WFS), M-8(10%WFS), M-9(15%WFS) and M-10(20%WFS), respectively. At 28 days, modulus of elasticity of control concrete mix M-6 (0% WFS) was 29.9 GPa. Increase in MOE by

1.7%, 2.9%, 4.8% and 3.9% of M-7, M-8, M-9 and M-10 concrete mixes, respectively when compared with control mix M-6 (29.9GPa). At 91 days, concrete mixes M-7, M-8, M-9 and M-10 achieved an increase of 1.3, 3.9, 5.2 and 4.5% in modulus of elasticity values in comparison with 30.6GPa. Similar trend was observed at 365 days. Higher value showed by mix M-9(15%WFS) was 34.1 GPa. It increased by 5.6% than modulus of elasticity of mix M-1(32.3 GPa).

Effect of age on modulus of elasticity

Effect of age on modulus of elasticity of concrete mixes made with and without waste foundry sand (WFS) is shown in Fig 4.14. Mix M-6 (0% WFS) achieved MOE of 25.7 GPa at 7 days, 29.9 GPa at 28 days, 30.6GPa at 91 days and 32.3GPa at 365 days. Maximum increase was observed 32.3 GPa at 365 days.

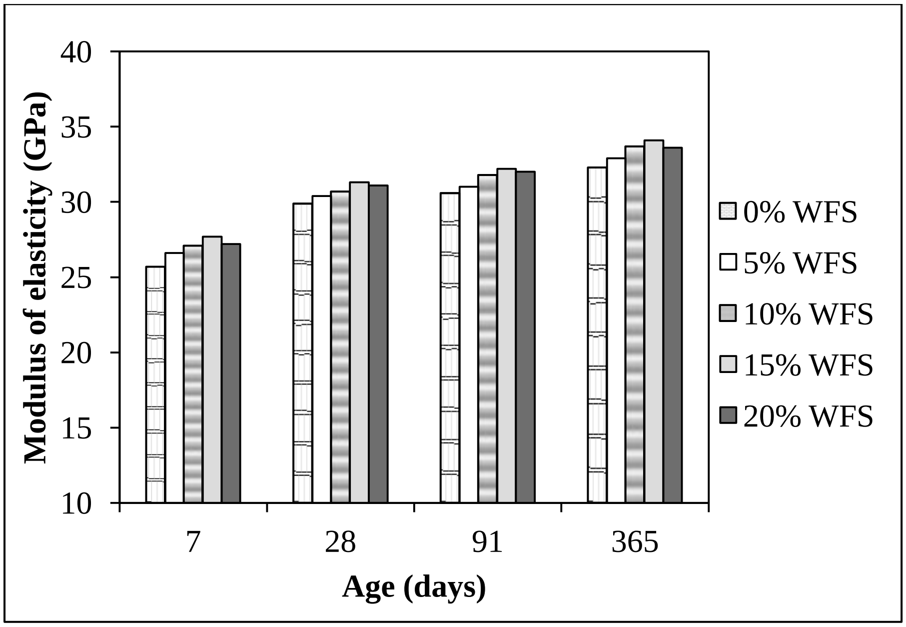


Fig. 4.14: Modulus of Elasticity verses Age

At the age of 7 days, modulus of elasticity of mix M-7(5% WFS) was 26.6 GPa, it increased to 30.4, 31 and 32.9 GPa at the age of 28, 91 and 365 days; percentage increase of 14.1, 16.5 and 23.3%, when compared with 7 days strength. Mix M-8 (0% WFS) achieved modulus of elasticity 27.1 GPa at 7 days. It was increased by 13.3% at 28 days, 17.3% at 91 days and 24.4% at 365 days. Similar trend was observed for mix M-9(15% WFS) and mix M-10(20% WFS). Mixes M-9 and M-10 achieved MOE 34.1GPa and 33.6 GPa at 365 days; an increase of 23.1% and 23.7% in comparison with 7-day modulus of elasticity 27.7 GPa and 27.2 GPa respectively.

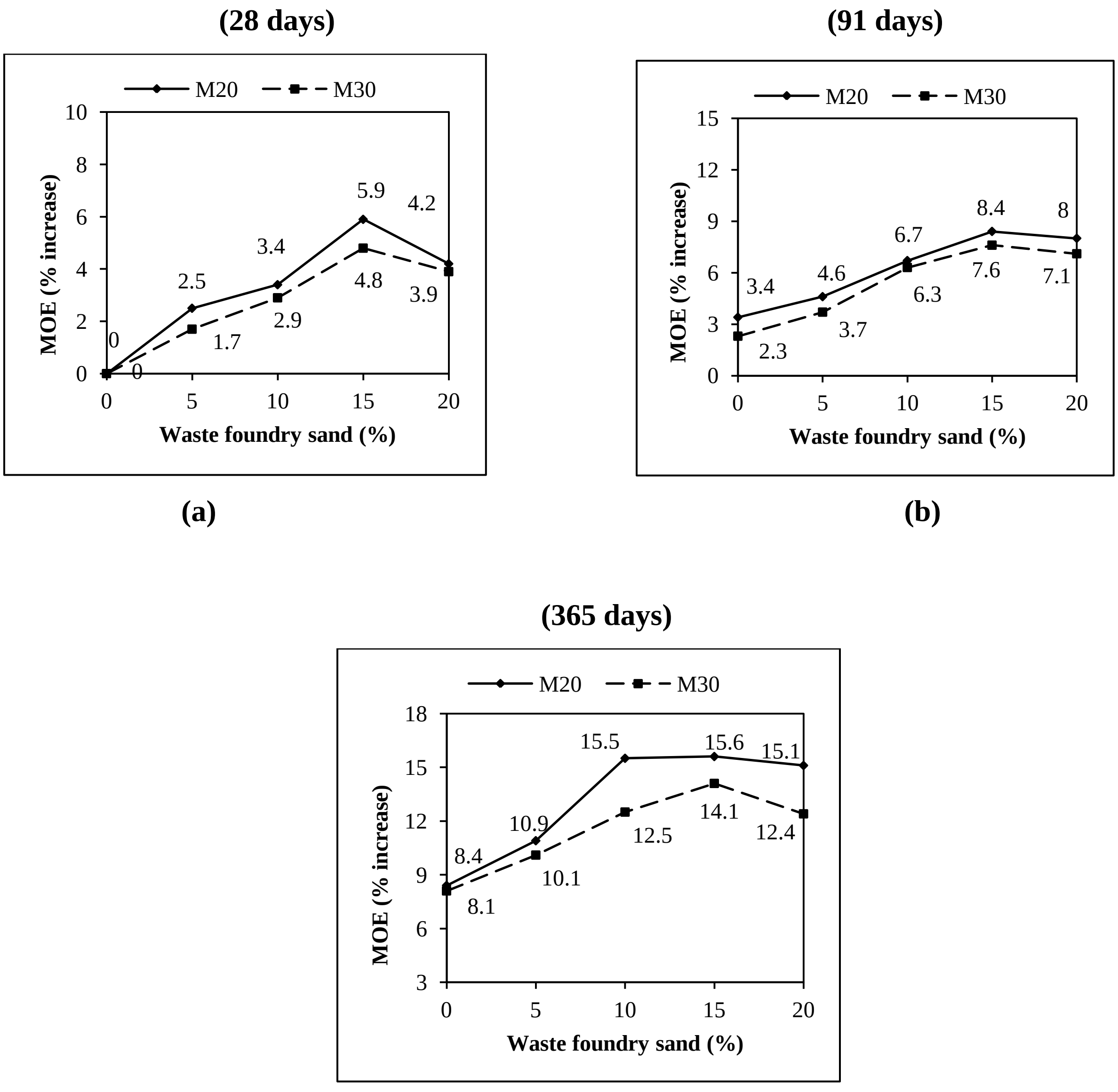
With the increase in age from 28 to 91 days, % increase in MOE of mixes M-6, M-7, M-8, M-9 and M-10 were 2.3%, 1.97%, 3.6%, 2.9% and 2.9%. Similarly, percentage increase was observed 5.5% for M-6, 6.12% for M-7, 6% for M-8, 5.9 % for M-9 and 5% for concrete mix M-10 between 91 to 365 days.

According to Guney et al (2010) static modulus of elasticity is a function of the compressive strength of concrete. If the compressive strength of concrete increases then static modulus of elasticity also increases. Concrete exhibited similar modulus of elasticity as that of control concrete mixture at 10% replacement of natural sand with WFS. Siddique et al. (2009) concluded that foundry sand marginally enhanced the modulus of elasticity of concrete mixtures. Modulus of elasticity increased from 5% to 12% at all age when percentage of WFS content increased in concrete mixtures.

4.4.3 Comparison between M20 and M30 Grades Of Concrete

Comparison between the modulus of elasticity of M20 and M30 Grades of concrete is shown in Fig 4.15 at the age of 28, 91 and 365 days. Percentage increase in modulus of elasticity increased with the inclusion of WFS in concrete for both grades of concretes. M20 Grade of concrete mixes showed better enhancement of value of MOE than M30 Grade of concrete mixes; similar to the results of in compressive strength and splitting tensile strength, comparison was evaluated on the basis of percentage increase. The percentage increase was calculated in comparison with the 28-day modulus of elasticity of mixes M-1(0%WFS) and M-6(0%WFS) for M20 and M30 Grades of concrete. It can be observed from this figure that inclusion of WFS has more pronounced effect on M20 Grade of concrete mixes than M30 Grade of concrete mixes. At the age of 28 days, MOE of M20 Grade concrete mixes increased by 0.3% to 1.1% than M30 Grade concrete mixes. It was increased by 0.4% to 1.1% at 91 days and 0.3% to 3.3% at 365 days of curing. Maximum percentage increase was found at 15% replacement for both grades of concrete. .

Modulus of elasticity is directly depends on compressive strength. If compressive strength increases, Modulus of elasticity increases or vice versa. The same aspect has been reflected by compressive strength and slitting tensile strength.



(a)

(b)

(c)

Fig. 4.15: Modulus of Elasticity (MOE) verses WFS at 28, 91 and 365 Days

4.5 ABRASION RESISTANCE

Abrasion of the concrete occurs due to scraping, rubbing, skidding or sliding of objects on its surface**.** The abrasion resistance of concrete is influenced by a number of factors such as mechanical properties of concrete (compressive strength), surface finish, aggregate properties, types of hardeners and curing. Abrasion resistance is measured in terms of depth of wear. Reduction in depth of wear indicated enhanced (increased) abrasion resistance and vice-versa.

4.5.1 Abrasion Resistance of M20 Grade (30MPa) Concrete

Effect of WFS on abrasion resistance

Effect of waste foundry sand (WFS) on abrasion resistance of concrete mixes at the age of 28, 91 and 365 days is shown in Figs. 4.16 to 4.19. Fig. 4.16 presents the variation of abrasion resistance (at 60 minutes) with varying percentages of waste foundry sand at various ages.

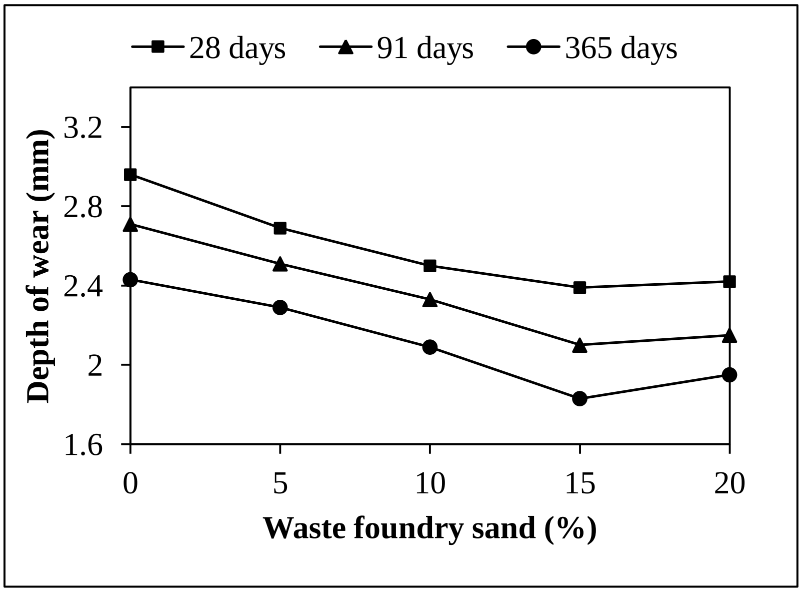


Fig. 4.16: Depth of Wear (60 min.) verses Waste Foundry Sand

At 60 minutes of abrasion, depth of wear for control mix M-1 (0% WFS) was 2.96 mm at 28-day, whereas it was found to be 2.69, 2.50, 2.39 and 2.42mm for mixes M-2(5%WFS), M-3(10%WFS), M-4(15%WFS) and M-5(20%WFS), respectively. At the age of 91 days, depth of wear for mix M-1 was 2.71 mm, 2.51mm for mix M-2, 2.33 for mix M-3, 2.1mm for mix M-4 and 2.15mm for mix M-5. Similarly, at 365days, 2.43mm wear depth was observed for mix M-1(0% WFS). With increasing WFS content in concrete, it reduced to 2.29 mm for mix M-7, 2.09 mm for mix M-8, 1.83 mm for mix M-9 and 1.95 mm for mix M-10.

The inclusion of WFS enhanced the abrasion resistance (depth of wear decreased) with the increase in WFS content. Mix M-4(15%WFS) showed maximum resistance against wear. Abrasion resistance for mix M-4 increased by 19.25% at 28 days, 22.5% at 91 days and 24.6% at 365 days in comparison with the M-1(0%WFS).

Figs. 4.17-4.19, present the variation of resistance with time for all mixes at the ages of 28, 91 and 365 days, respectively. From these figures, it can be seen that the depth of wear increased with abrasion time for all mixes. The depth of wear also decreased with the increase in age of mixes.

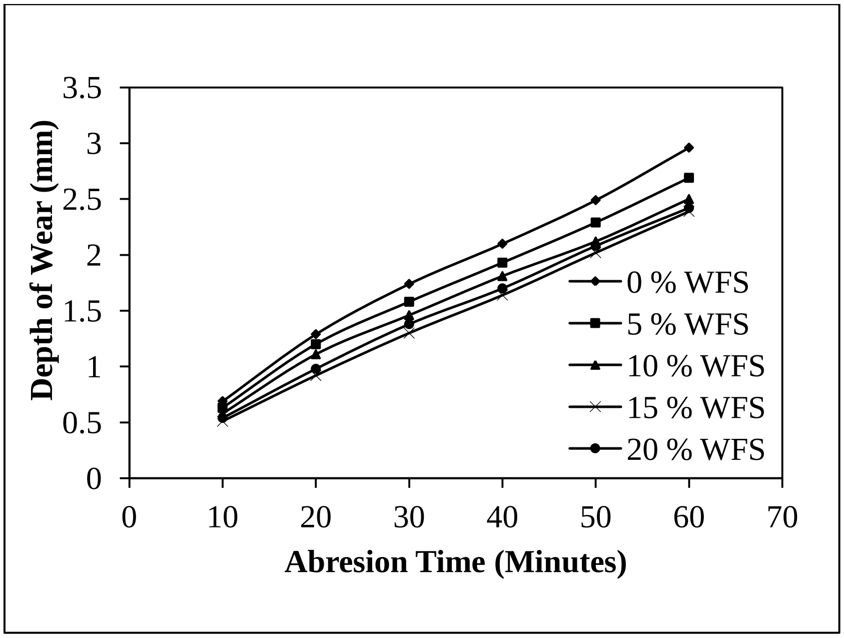


Fig. 4.17: Depth of Wear (28 days) verses Abrasion Time

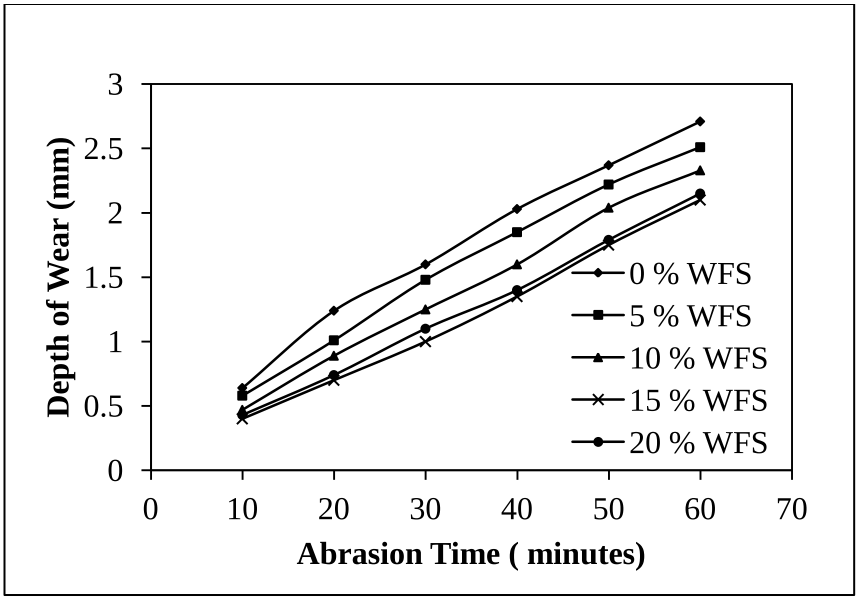


Fig. 4.18: Depth of Wear (91 days) verses Abrasion Time

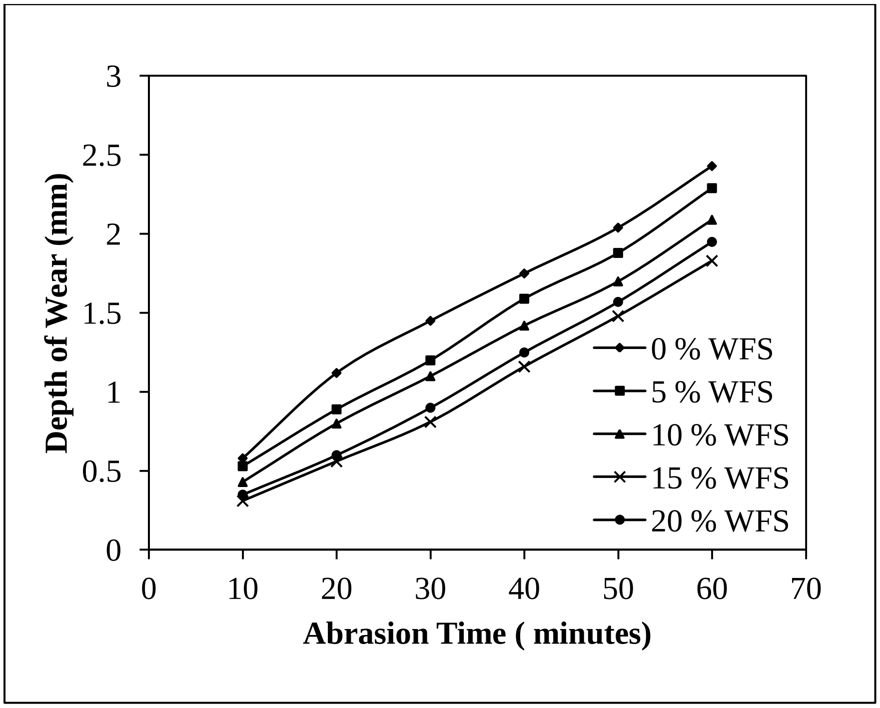


Fig. 4.19 Depth of Wear (365 days) verses Abrasion Time

Effect of age on abrasion resistance

Influence of age on abrasion resistance of concrete mixes with and without WFS at the age of 28, 91 and 365 days is shown in Fig 4.20. For all concrete mixes, the depth of wear decreased with the increase in curing time (age) indicating better abrasion resistance (reduction in depth of wear).

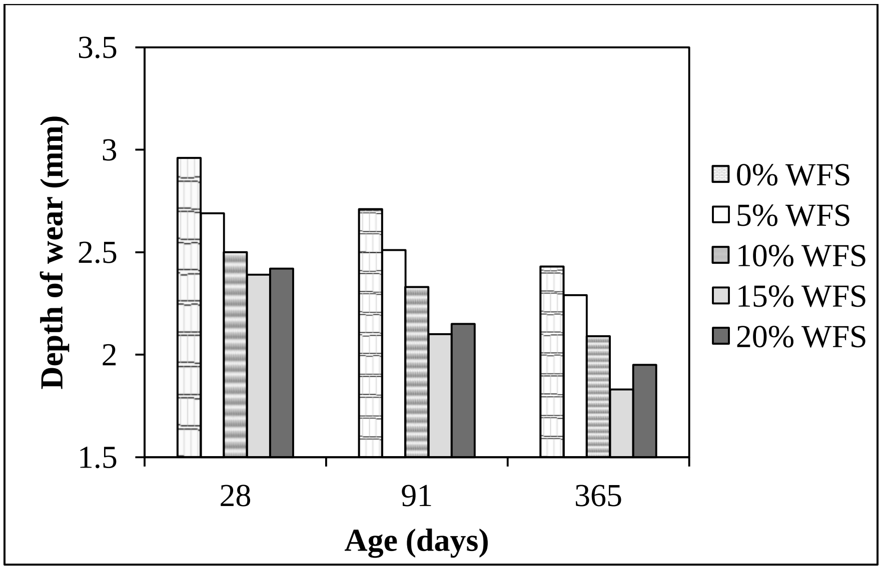


Fig. 4.20: Depth of Wear (60 min.) verses Age

It can be seen from Fig. 4.20 that abrasion resistance of mixes M-2(5%WFS), M-3(10%WFS), M-4(15%WFS) and M-5(20%WFS) containing 5, 10, 15and 20% waste foundry sand was lower than that of the control mix M-1(0%WFS) at all ages. At 28 days, abrasion resistance increased by 9.12% to 19.25% when compared with abrasion resistance of mix M-1(2.96mm). At 91 day, depth of wear for mix M-1(0%WFS) was 2.71mm. It increased by 7.38% to 22.5%. Similar result was observed at 365 day. 2.43mm wear depth was observed for mix M-1(0% WFS). Percentage increase were found 5.76% for M-2(5%WFS), 13.99% for M-3(10%WFS), 24.6% for M-4(15%WFS) and 19.75% for mix M-5(20%WFS).

4.5.2 Abrasion Resistance of M30 Grade (40MPa) Concrete

Effect of WFS on abrasion resistance

Effect of WFS on abrasion resistance of M30 Grade of concrete is presented in Figs 4.21 to 4.24. For M30 Grade concrete mixes M-6 (0% WFS), M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS) and M-10 (20% WFS) exhibited more or less similar trends as that of M20 Grade concrete mixes. Variations of wear resistance at 60 minutes with and without waste foundry sand at the ages of 28, 91 and 365 days shown in Fig. 4.21.

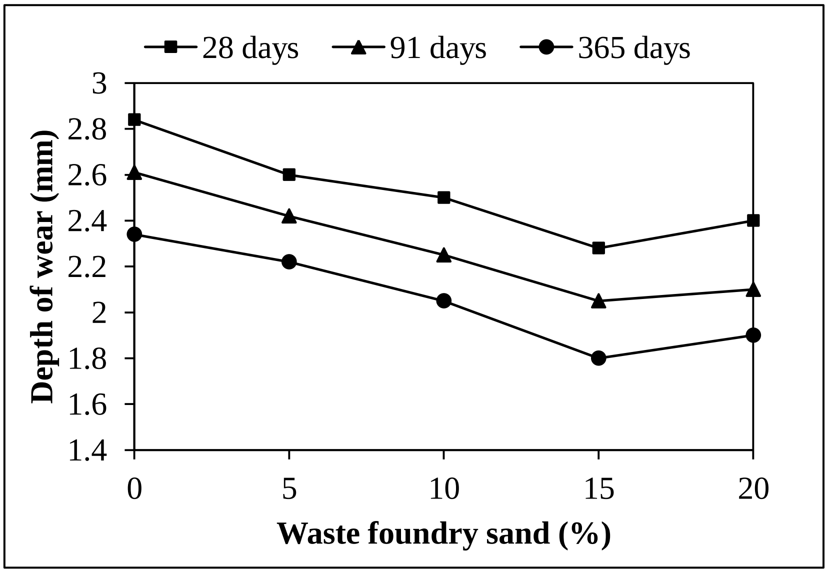


Fig. 4.21: Depth of wear (60min.) verses Waste Foundry sand

The depth of wear decreased (abrasion resistance increased) with increase in WFS content and age of curing for mixes M-6 (0% WFS), M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS) and M-10 (20% WFS). Depth of wear of mix M-1(0% WFS) at 28 days was 2.84mm, whereas depth of wear of concrete mixes containing waste foundry sand (5, 10, 15 and 20%) exhibited 2.6, 2.5, 2.31 and 2.4mm which are less than 2.84 mm for mix M-1 (0% WFS). Inclusion of WFS enhanced the abrasion resistance (reduction in depth of wear) of concrete. At 91 days, wear depth for mix M-6 was 2.61mm. It decreased to 2.42, 2.22, 2.05 and 2.1mm for mixes M-7, M-8, M-9 and M-10 respectively. At 365days, 2.34mm wear depth was found for mix M-1(0% WFS).

With increasing WFS content in concrete, depth of wear reduced to 2.22mm for M-7, 2.05mm for M-8, 1.80mm for M-9 and 1.9mm for M-10.

At 60 minutes of abrasion, all mix, with and without waste foundry sand, exhibited excellent resistance to abrasion. However, best results were obtained for mix M-9 (15% WFS) where depth of wear was 2.31mm, 2.05mm and 1.8mm at 28, 91 and 365 days, respectively.

Figs 4.22- 4.24 present the depth of wear of all mixes with respect to abrasion time at the ages of 28, 91 and 365 day of curing. It exhibited that with increase in abrasion time, depth of wear increased but also reduced with inclusion of waste foundry sand in concrete mixes. Mix M-9(15%WFS) shows better abrasion resistance against wear than all other mix at all age.

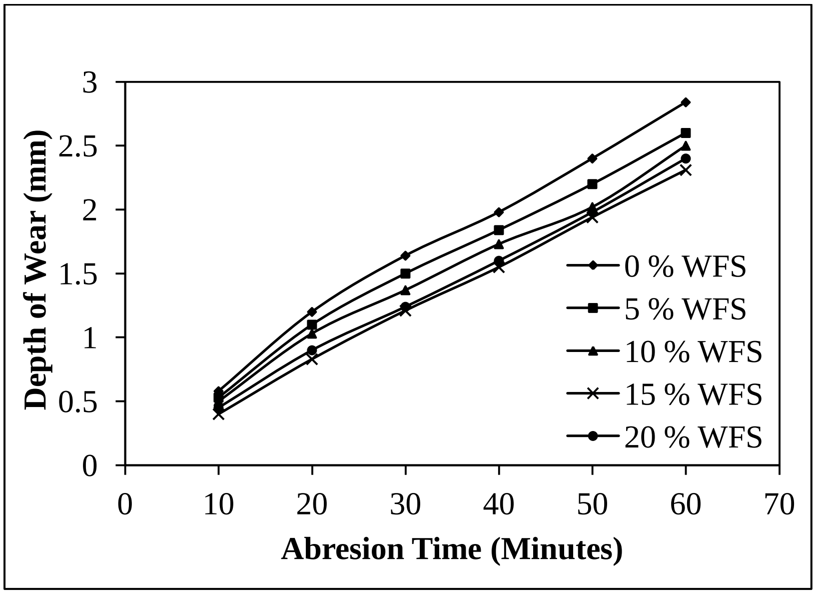


Fig. 4.22: Depth of Wear (28 days) verses Abrasion Time

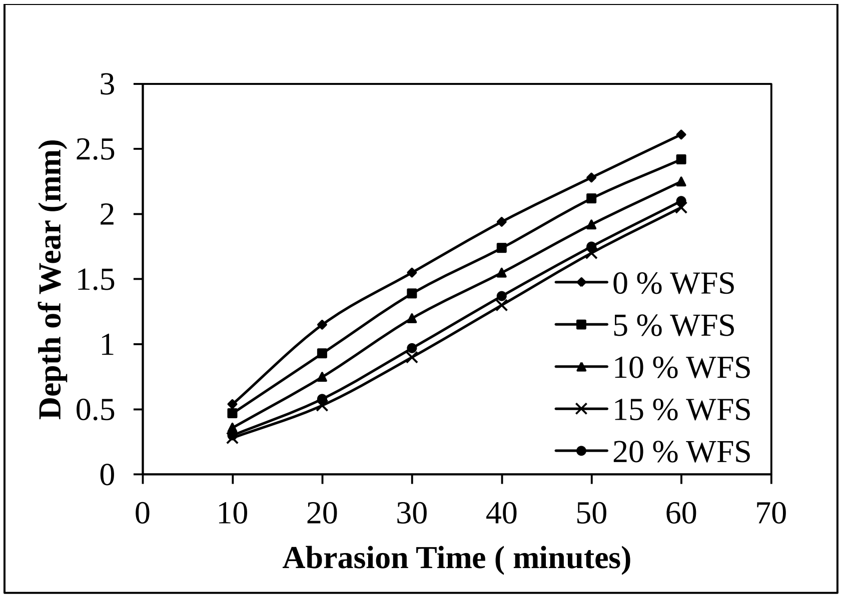


Fig. 4.23: Depth of Wear (91 days) verses Abrasion Time

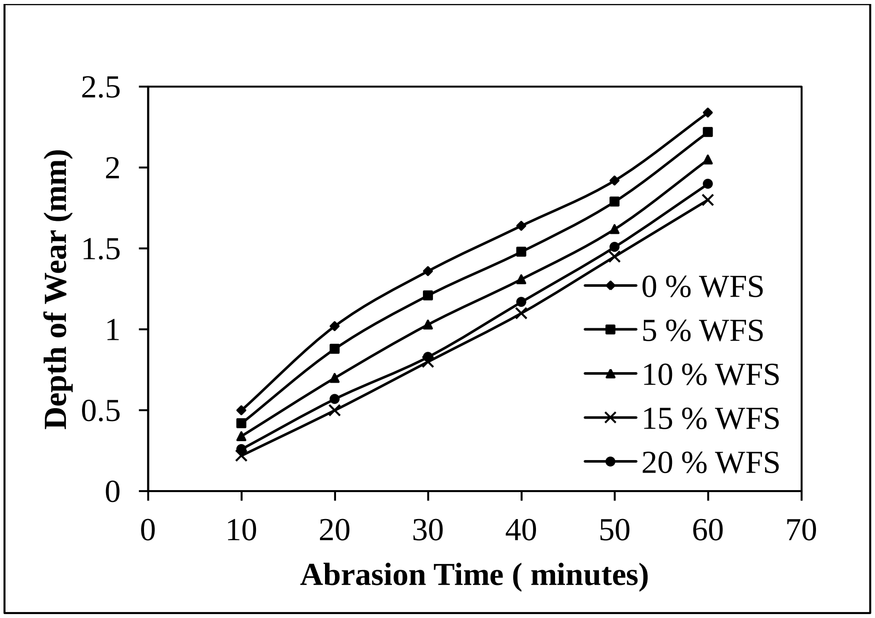


Fig. 4.24: Depth of Wear (365 days) verses Abrasion Time

Effect of age on abrasion resistance

Effect of the age on concrete mixes M-6 (0% WFS), M-7 (5% WFS), M-8 (10% WFS), M-9 (15% WFS) and M-10 (20% WFS) is shown in Fig 4.25. As can be expected, the abrasion resistance of concrete mixes continued to increase with age.

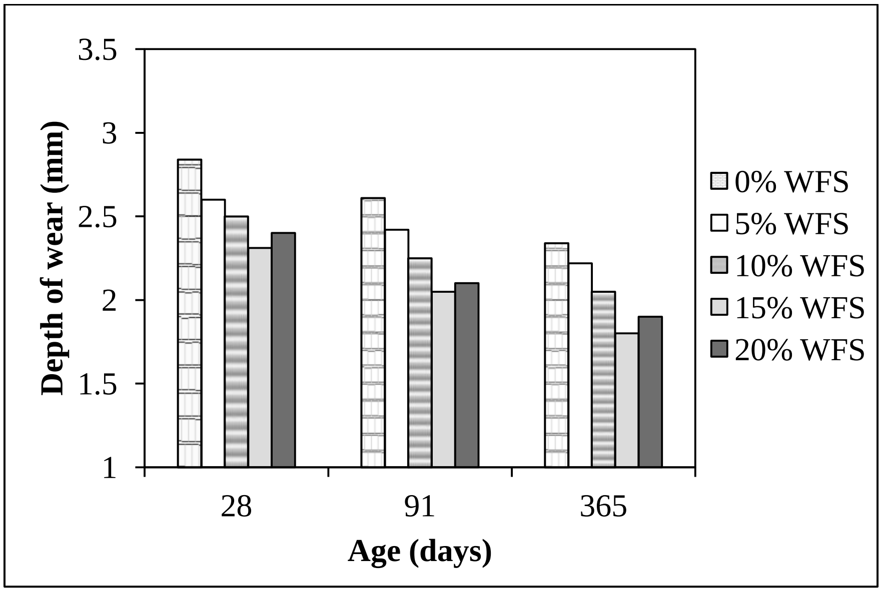


Fig. 4.25: Depth of Wear verses Age

Abrasion resistance for mix M-6(0%WFS) increased by 8.81% at 91 days and 17.6% at 365 days. Similarly, there was increase of 6.92% to 11.62% for mix M-7(5%WFS); 11.1% to 18% for mix M-8(10%WFS); 12.68 to 22.1% for mix M-9(15%WFS) and 12.5% to 20.8% for mix M-10(20%WFS), respectively when compared with 28-day depth of wear of the same mixes. For all concrete mixes, the depth of wear decreased with the increase in age indicating better abrasion resistance. Also the presence of increasing amount of waste foundry sand enhanced the abrasion resistance in that the depth of wear decreased with the increasing in WFS content.

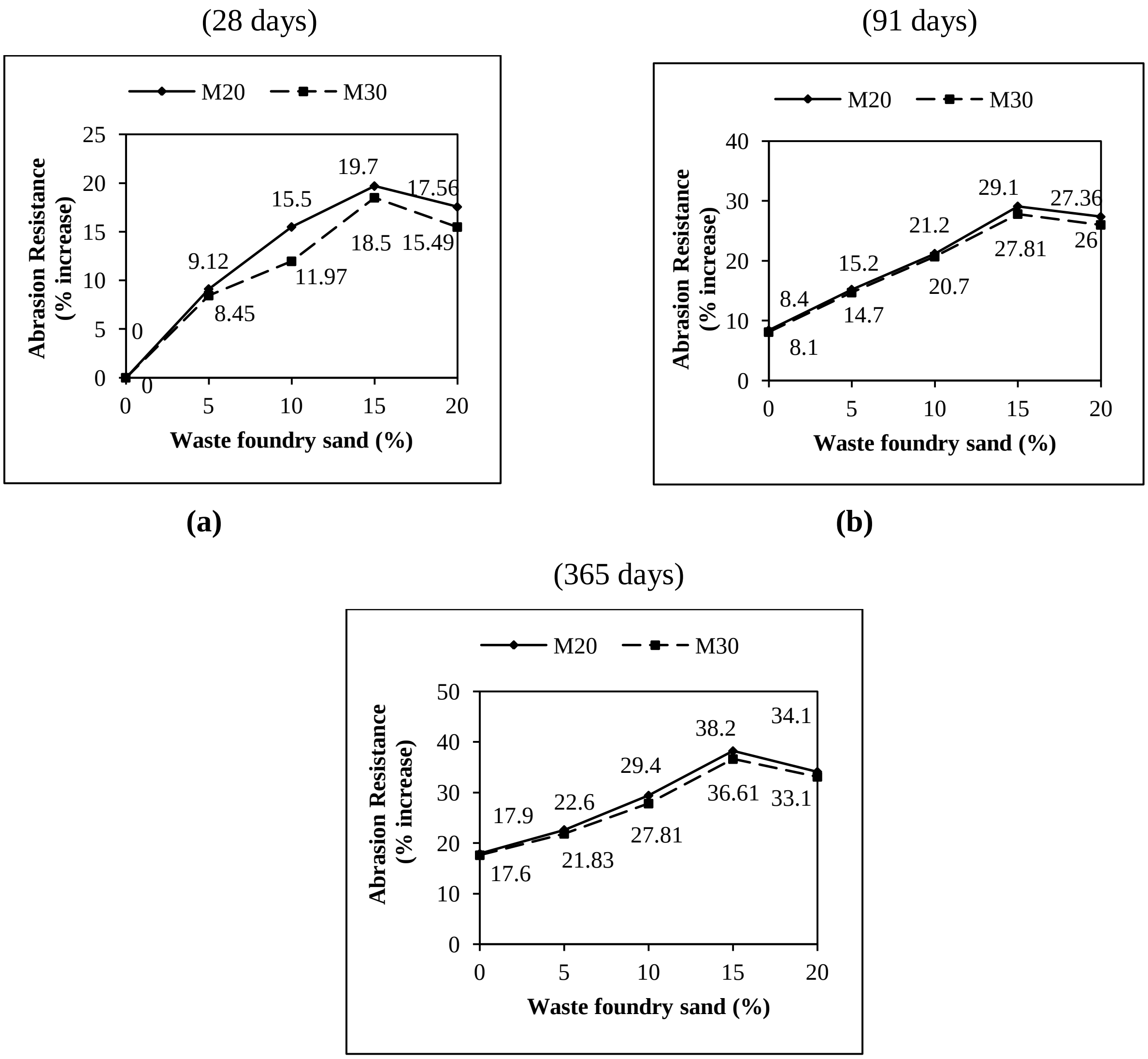
Abrasion resistance of concrete increased with the increase in WFS content up to 15% WFS for both grades of concrete (M20 and M30), which indicate that concrete became more dense. This aspect has also been reflected by the results of compressive strength, splitting tensile strength and modulus of elasticity up to 15% WFS for both grade of concrete. This can be due to presence of fine particle of WFS in concrete mixtures. This indicated that for a particular percentage of WFS depth of wear decreased with increase in age, which means that wear resistance of concrete mixes increased with age.

The wear resistance of concrete is primarily dependent on its compressive strength. Therefore, air-entrainment, water-cement ratio and types of aggregates and their properties, which have an influence on the compressive strength of concrete, should also have an effect on its wear resistance. This is possibly due to the increase in compressive strength resulting from increased maturity of concrete with age and densification of the concrete matrix. Wear test results indicate that the compressive strength was an important factor affecting the wear resistance of the concrete.

Not much work has been reported on abrasion resistance of concrete containing waste foundry sand. However, Nail et al. (1997) carried out experiments on non air entrained concrete and air entrained concrete. They concluded that, all mixtures with and without foundry sand/fly ash exhibited excellent resistance to abrasion. At the age of 182 days all concrete mixtures containing fly ash and used foundry sand showed an increase in resistance to abrasion compared with the 28-day age results. At the age of 28 days air-entrained concrete mixtures with used foundry sand and fly ash content, displayed high resistance to abrasion. They all passed ACI/ASTM accepted criteria

4.5.3 Comparison between M20 and M30 Grades of Concrete

Comparison between abrasion resistance of M20 and M30 Grades of concrete is shown in Fig. 4.26. Abrasion resistance was evaluated in term of depth of wear. Percentage increase was calculated to know the effect of waste foundry sand (WFS) on both grades of concrete mixes. Very marginal increase was observed for M20 Grade of concrete mixes than M30 Grade of concrete mixes. Abrasion resistance directly depends upon the hardness of concrete surface. With inclusion of WFS in concrete up to 15% replacement of fine aggregate, concrete surface become harder than control mix for both grades of concrete. So due to increase in hardness, abrasion resistance increased. This is due to the packing effect of fine particles of WFS. Particles are well packed between the voids of M20 Grade concrete matrix than M30 Grade concrete matrix. After 15% WFS content, abrasion resistance decreased. It could be probably due to the presence of loose particles of WFS in matrix. It means that 15% WFS in concrete is sufficient to fill the voids between the particles of matrix. For M20 Grade of concrete, abrasion resistance increased by 0.67% to 3.53% at 28 days, 0.3% to 1.36% at 91 days and 0.3% to 1.59% at 365 days.



(a) **(b)**

(c)

Fig. 4.26: Abrasion Resistance (AR) verses WFS at 28, 91 and 365 Days

4.6 RAPID CHLORIDE PERMEABILITY TEST (RCPT)

4.6.1 Rapid Chloride Permeability of M20 Grade (30MPa) Concrete

Effect of WFS on rapid chloride permeability

Influence of WFS on chloride-ion permeability of concrete mixes M-1(0%WFS), M-2(5%WFS), M-3(10%WFS), M-4(15%WFS) and M-5(20%WFS) are shown in Fig. 4.27.

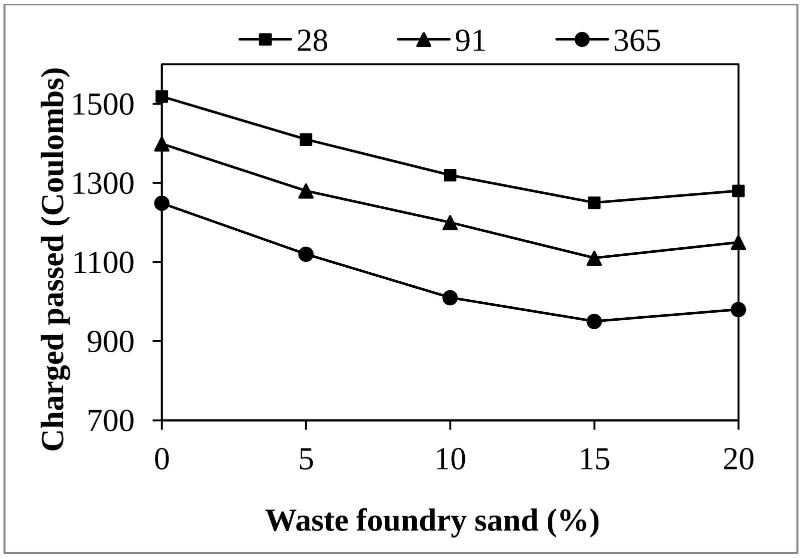


Fig. 4.27: RCPT verses Waste Foundry Sand

Chloride-ion permeability of concrete mixes decreased with the increase in WFS content. At 28 days, for mixes M-1 (0% WFS), M-2 (5% WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS), charges passed were 1519, 1410, 1320, 1250 and 1280 coulombs. Similarly, coulombs charge passed were 1399, 1290, 1200, 1110 and 1150 the age of 91 days. At the age of 365 days, charges passed were 1249, 1120, 1010, 950 and 980 coulombs. Coulombs charges passed at 365 days are less than those of 28 days and 91 days. Coulomb value decreased in mix M-4 with the increase in WFS content up to 15% WFS, which indicate that concrete became more dense. This aspect has also been reflected by the compressive strength results of concrete mix made with WFS up to 15% WFS. However, at 20% WFS (M-5), there is slight increase in coulomb value with references to 15% WFS. All concrete mixes have Low Permeability (coulombs between 1000 and 2000) as per ASTM C1202. It can be seen that RCPT values decreased with the increase in WFS content (%). Maximum reduction in RCPT value was observed at 15% WFS. It can be concluded that at 15% WFS, concrete mix M-4 exhibited more resistance to chloride-ion penetrability than control mix M-1 (0% WFS). According to ASTM C 1202, all concrete mixes have low penetrability to chloride-ion. At 365 days, mixes M-4 (15%WFS) comes under the category of very low chloride-ion penetrability.

Effect of age on rapid chloride permeability

Effect of age on rapid chloride penetration into concrete mixes of M20 Grade of concrete at 28, 91 and 365 days is shown in Fig. 4.28.

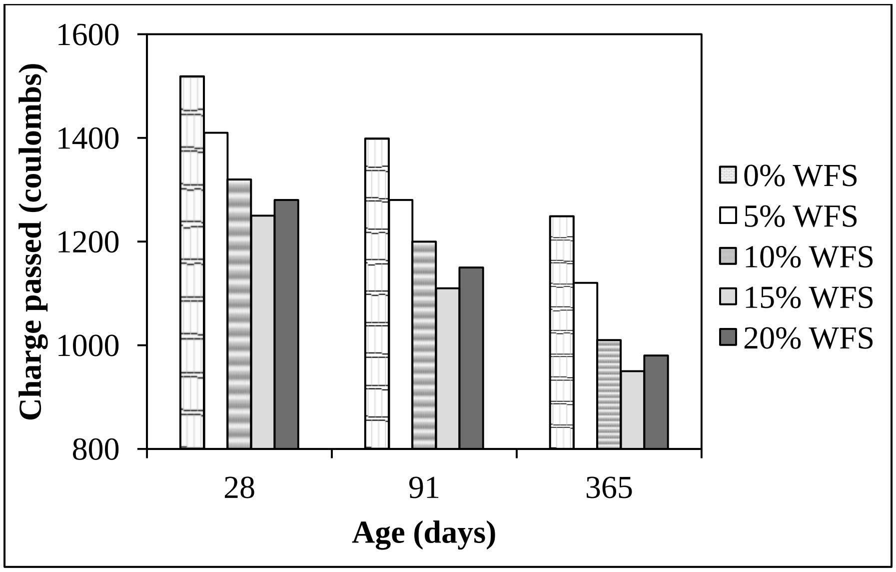


Fig. 4.28: RCPT verses Age

It can be seen that, RCPT value decreased with the increase in age. Total charge passed for mix M-1(0%WFS) were 1519, 1399 and 1249 coulombs at the age of 28, 91 and 365 days respectively. For mix M-2 (5%WFS), charges passed were 1410 coulombs at 28 days, 1280 coulombs at 91 days and 1120 coulombs at 365 days,. For mix M-3(10%WFS), charge passed were 1320, 1200 and 1010 coulombs at 28, 91 and 365 days. Coulombs charge passed at 28, 91 and 365 days were 1250, 1110 and 950 for concrete mix M-4(15%WFS). Similarly, values of RCPT for mix M-5(20%WFS) were 1280, 1150 and 980 coulombs at the age of 28, 91 and 365 days respectively. RCPT value for mix M-4 (15% WFS) was found to be less than mixes M-1, M-2, M-3 and M-5. Minimum value was observed for mix M-4 at all age. The 15% replacement of WFS acts as filler material and yields a significant reduction in total charge passed.

The concrete mixes M-1, M-2, M-3, M-4 and M-5 showed decrease in RCPT value between 28 to 91 days, by 7.9, 9.2, 9.1, 12.61 and 10.15% respectively. Similar trend was observed between 91 to 365 days (Fig 4.17). RCPT values of all mixes are continued to decrease with the increase in age. It was decreased by 10.72% for mix M-1(0% WFS), 12.5% for mix M-2 (5% WFS), 15.8% for mix M-3 (10% WFS), 14.4% and 14.3% for mixes M-4 (15% WFS) and M-5 (20% WFS) respectively.

4.6.2 Rapid Chloride Permeability of M30 Grade (40MPa) Concrete

Effect of WFS on rapid chloride permeability

Effect of WFS in M30 Grade of concrete mixes M-6(0%WFS), M-7(5% WFS), M-8(10% WFS), M-9(15% WFS) and M-10(20% WFS) is shown in Fig. 4.29.

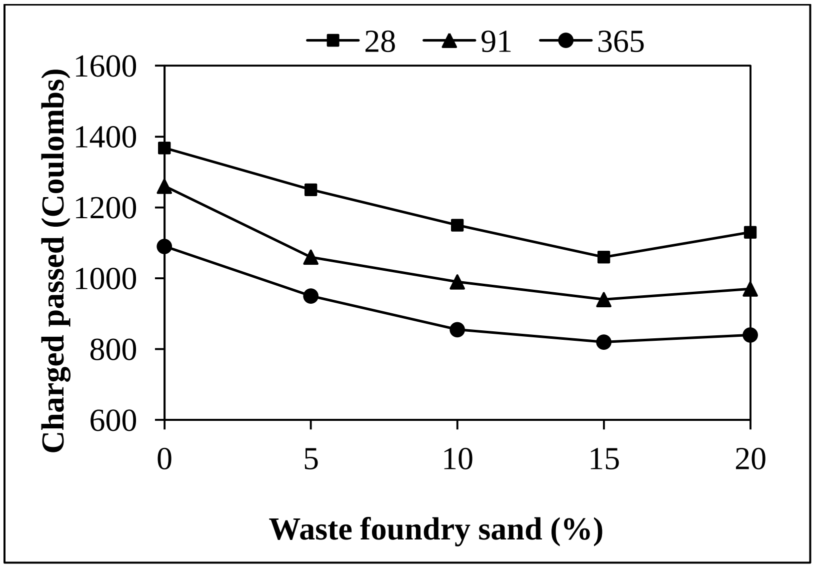


Fig. 4.29: RCPT verses Waste Foundry Sand

Similar trends in results were observed for M30 Grade concrete mixes (M-6, M-7, M-8, M-9 and M-10), like that of M20 Grade concrete mixes. At 28 days, coulombs charge passed were 1368, 1250, 1150, 1060 and 1130 for mixes M-6(0% WFS), M-7(5% WFS), M-8(10% WFS), M-9(15% WFS) and M-10(20% WFS). Minimum charge was passed in Mix M-9(1060 coulombs). Coulombs charged passed at 91 days were 1260, 1060, 990, 940 and 970 coulombs. Mix M-8 (10% WFS) and M-9 (15% WFS) and M-10 comes under very low chloride ions penetrability as per ASTM C1202. Charge passed at 365 days were 1090, 950, 855, 820 and 840 coulombs. Coulombs charges passed at 365 days are less than those of 91 days and 28 days, which indicate that concrete microstructure become denser. This is possible because of presence of fine particle of WFS in concrete mixes. These fine particles reduce the voids between ingredient of concrete and makes dense matrix. It also helps to decrease the electrical conductance of concrete.

Effect of age on rapid chloride permeability

Effect of Age on rapid chloride permeability of concrete mixes of M30 Grade of concrete is shown in Fig. 4.30. With increasing age, permeability of concrete mixes is found to decrease.

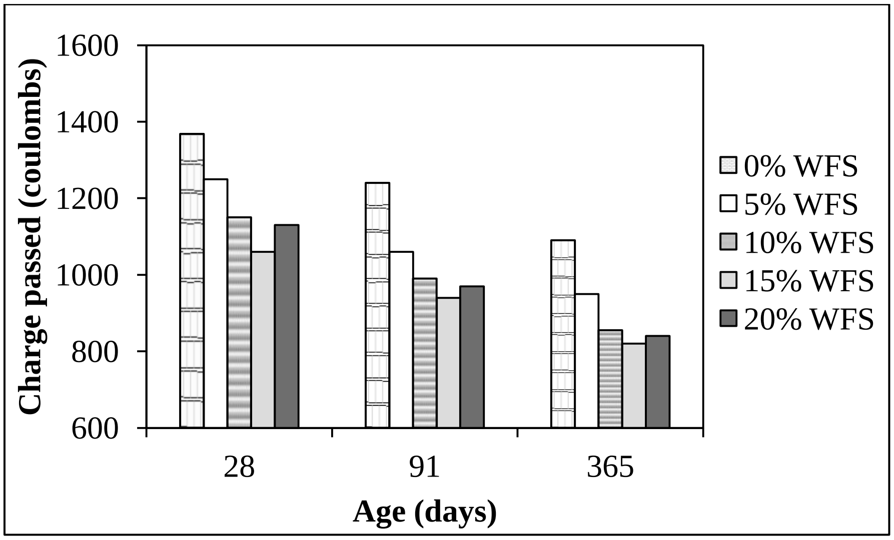


Fig. 4.30: RCPT verses Age

At the ages of 28, 91 and 365 days, total charge passed for mix M-6(0%WFS) were 1368, 1260 and 1090 coulomb respectively. Charge passed were 1250, 1060, 950 coulomb for M-7(5% WFS) and 1150, 990, 885 coulomb for M-8(10% WFS) at the age of 28, 91 and 365 days respectively. Mix M-7 comes under very low chloride permeability rating at 365 days, where as mix M-8 comes under low chloride permeability at the age of 91 and 365 days. For mix M-

9(15%WFS), charge passed at 28 days were 1060 coulomb, 940 coulomb at 91 days and 820 coulomb at 365 days. Similarly, total charge passed were for mix M-10(20%WFS) were 1130, 970 and 840 coulombs at 28, 91 and 365 days. Maximum resistance against chloride permeability showed by mix M-9(15% WFS) at all age. At 15% replacement of natural sand with WFS, WFS gives better effect to internal pore structure of concrete as a filler material.

With the increase in age from 28 to 91 days, % decrease in chloride permeability of mixes M-6, M-7, M-8, M-9 and M-10 were 7.9, 15.2, 13.91, 11.32 and 14.15% respectively. Similarly % decrease was observed 13.5% for M-6, 10.37% for M-7, 13.63% for M-8, 12.76 % for M-9 and 13.40% for concrete mix M-10 between 91 to 365 days.

Not much work has been reported on rapid chloride permeability of concrete containing waste foundry sand. However, Nail et al. (1997) carried out experiments on non air entrained concrete and air entrained concrete. They concluded that, Use of used foundry sand and fly ash improved chloride-ion penetration resistance of concrete. The chloride-ion penetration decreased from moderate to low when used foundry sand content was increased up to 20% and fly ash increased up to 34% at the age of 56 days.

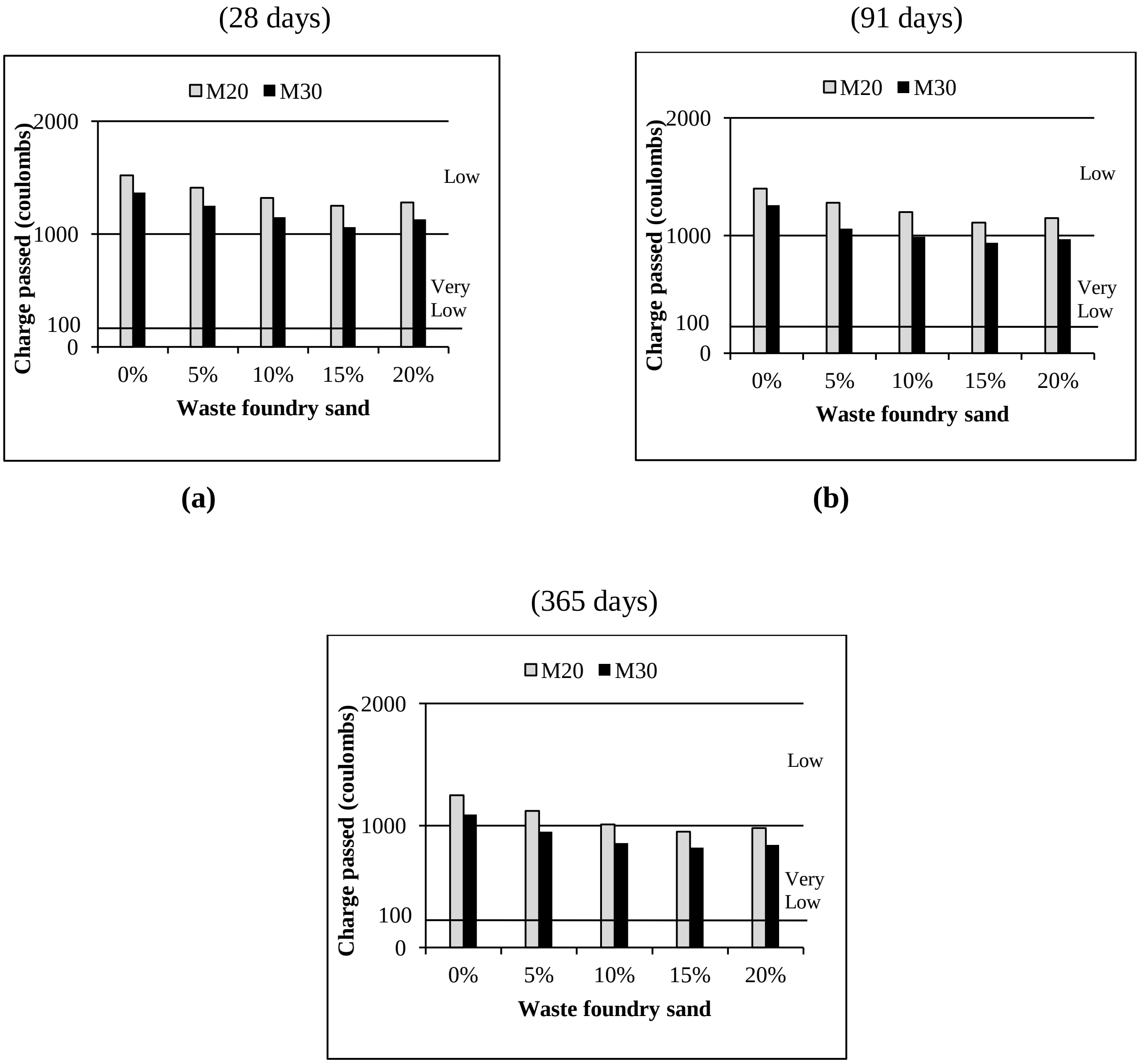
Similar results obtained for non-air entrained concrete. At the age of 56 days addition of used foundry sand and fly ash to the concrete improved the resistance to chloride. At the age of 182 days, all concrete mixtures, except one, had very low chloride permeability rating. In general, all concrete with used foundry sand performed equivalent to or better than no-foundry sand concrete.

4.6.3 Comparison between M20 and M30 Grade of concrete

Rapid chloride permeability was evaluated on the basis of charge passed (coulombs). Charge passed for M20 and M30 Grades of concrete mixes at different percentage of WFS are shown in Fig. 4.31.

At 28 days, M20and M30 Grades of concrete mixes come under ‘low’ chloride ions penetrability (1000 to 2000 coulombs). At the age of 91 days, M30 Grade of concrete mixes (M-8, M-9 and M-10) come under ‘very low’ chloride ion penetrability (100 to 1000 coulombs) and M20 Grade of concrete mixes (M-1 to M-5) come under ‘low’ chloride penetrability. Similarly, at the age of

365 days, concrete mixes of both grades of concrete falls under ‘very low’ chloride ions penetrability except mixes of 0% replacement (M-1 and M-6). It means that increase in WFS content in concrete led to the decrease in the chloride ions permeability at all age. Finer particles of WFS act as a good filler material to make a stronger internal structure of concrete matrix. As per ASTM C1202, chloride ions penetrability based on charge passed given in Table 3.18



(a) **(b)**

(c)

Fig. 4.31: Rapid Chloride Permeability Verses WFS at 28, 91 and 365 Days

4.7 DEICING SALT SCALING RESISTANCE

The test method (ASTM C 672) deals with the procedure for determining the resistance to scaling of a horizontal concrete surface exposed to freezing and thawing cycle in the presence of deicing chemicals. The surface scaling resistance was evaluated by visual examination and rating for deicing salt surface scaling is given in Table 3.16. Scaling resistance was also evaluated on the basis of total amount of scaling residue (mass loss).

4.7.1 Deicing Salt Scaling Resistance of M20 Grade (30MPa) Concrete

Effect of WFS on deicing salt scaling resistance

Effect of waste foundry sand on deicing salt scaling resistance of concrete mixes in the form of visual rating as per ASTM C 672 is given in Table 4.1. At 28 days, Mix M-1(0%WFS) and mix M-2(5%WFS) exhibited rating of 2 (slight to moderate scaling) whereas ratings of mix M-3(10%WFS), M-4(15%WFS) and M-5(20%WFS) were 1 (very slight scaling). At 91 day, concrete mixes M-1 (0% WFS), M-2 (5% WFS) and M-3 (10% WFS) exhibited rating of 1 (very slight scaling) after 50 cycles of freezing and thawing in the presence of deicing salt. Mix M-4 (15% WFS) and M-5 (20% WFS) showed “no scaling”. Similarly at 365 day of curing, mixes M-2, M-3, M-4 and M-5 exhibited “no scaling” whereas Mix M-1(0%WFS) showed very slight scaling (rating 1).

Table 4.1 Visual Rating for Concrete Mixes as per ASTM C 672

Mix No.	WFS (%)	Visual rating (50 cycle)		
		28 day	90 Day	365 Day
M-1	0	2	1	1
M-2	5	2	1	0
M-3	10	1	1	0
M-4	15	1	0	0
M-5	20	1	0	0

Deicing salt scaling resistance of concrete mixes were also evaluated in term of mass loss (scaled off residue) shown in Fig.4.32. The mass of scaling residue decreased with increase in WFS content in concrete mixes.

At the age of 28 days, 1.06% to 0.78% of weight loss was observed for mixes M-1 (0% WFS), M-2 (5% WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS). Minimum weight loss was observed at 15% WFS content for mix M-4. At the age of 91 days, the percentage loss of mass of scaling residue was found 0.96% for mix M-1(0% WFS), 0.85% for mix M-2(5% WFS), 0.7% for mix M-3 (10% WFS), 0.56% for mix M-4 (15% WFS) and 0.65% for mix M-5(20% WFS). Similarly, at 365 days, concrete mixes M-1, M-2, M-3, M-4 and M-5 exhibited 0.79%, 0.70%, 0.57%, 0.50% and 0.55% mass loss respectively. The above results show that, at 15% replacement of sand with WFS, all concrete mix exhibited maximum scaling resistance against deicing chemical.

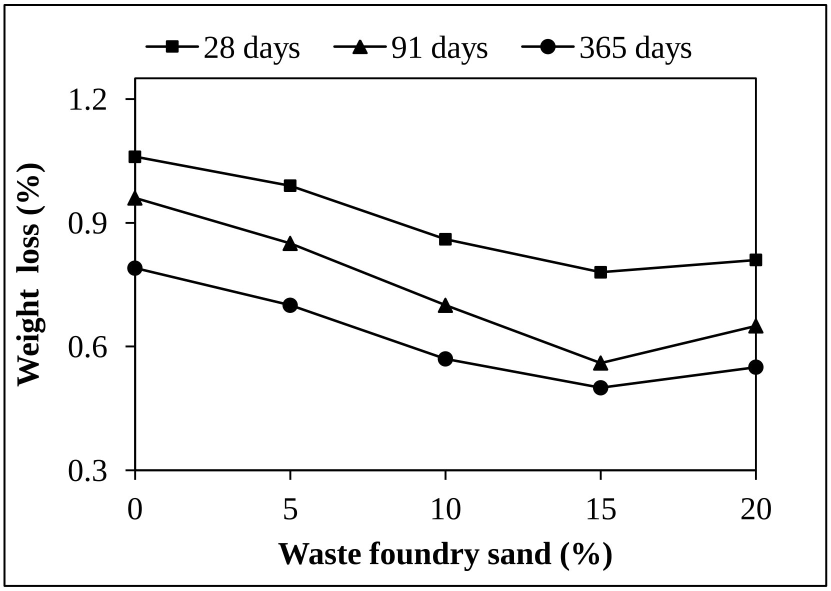


Fig. 4.32: Weight loss verses Waste Foundry Sand

Effect of age on deicing salt scaling resistance

Influence of age on deicing salt scaling resistance of concrete is shown in Fig 4.33. Scaling resistance was evaluated at the age of 28, 91 and 365 day. Scaling resistance of all concrete mixes increased with the increase of curing age. Weight loss was found to be 1.06% at 28-day, 0.96 at 91-day and 0.79% at 365-day for mix M-1(0%WFS). For mix M-2(5%WFS), it was 0.99%, 0.85% and 0.70% at 28, 91 and 365-day. Similarly, it was reduced to 0.86%, 0.70% and 0.57% for mix M-3(10%WFS); 0.78%, 0.56% and 0.50% for mix M-4(15%WFS); 0.81%, 0.65% and 0.55% for mix M-5(20%WFS) at the age of 28, 91 and 365 day. Minimum weight loss was observed for mix M-4 (15% WFS).

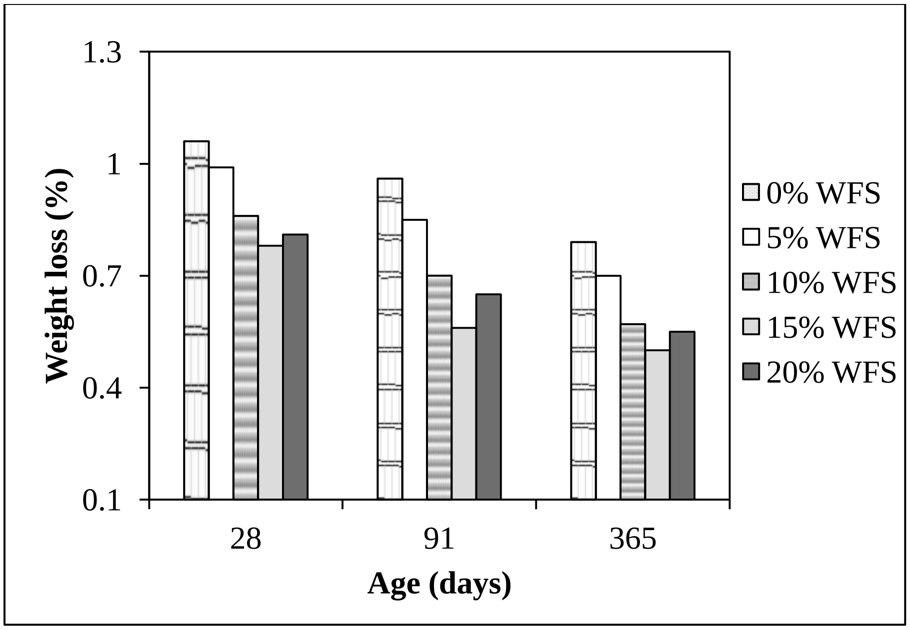


Fig. 4.33: Weight Loss verses Age

4.7.2 Deicing Salt Scaling Resistance of M30 Grade (40MPa) Concrete

Effect of WFS on deicing salt scaling resistance

Effect of WFS on deicing salt scaling resistance of concrete mixes is examined by visual rating as per ASTM C 672 (given in Table 4.2). At the age of 28 days, visual rating of mixes M-8(10%WFS), M-9(15%WFS) and M-10(20%WFS) were 1 (very slight scaling), and it was observed as 2 (slight to moderate scaling) for mix M-6(0%WFS) and M-7(5%WFS). At the age of 91 days, visual rating for mixes M-8, M-9 and M-10 were 0 (no scaling) and mixes M-7, M-8, M-9 and M-10 showed no scaling at the age of 365 day. It means, due to increase in waste foundry sand content in concrete and age of curing, concrete mixes (with WFS) become more stronger than control mix (0%WFS) against deicing chemical. Mass loss was observed 1.06% to 0.73% at 28 days, 0.9% to 0.5% at 91 days and 0.7% to 0.42% at 365 days.

Table 4.2 Visual Rating for M30 Concrete Mixes as per ASTM C 672

Mix No.	**WFS (%)**	**Visual rating (50 cycle)**		
		28 day	**90 Day**	**365 Day**
M-6	0	2	1	1
M-7	5	2	1	0
M-8	10	1	0	0
M-9	15	1	0	0
M-10	20	1	0	0

The mass of scaling residue of all the mixes at the age of 28, 91 and 365 day is presented in Fig 4.34. The mass of scaling residue at the end of 50 cycles of freezing and thawing cycle was low for the concrete mixes containing WFS (5, 10, 15 and 20%) at all age of curing.

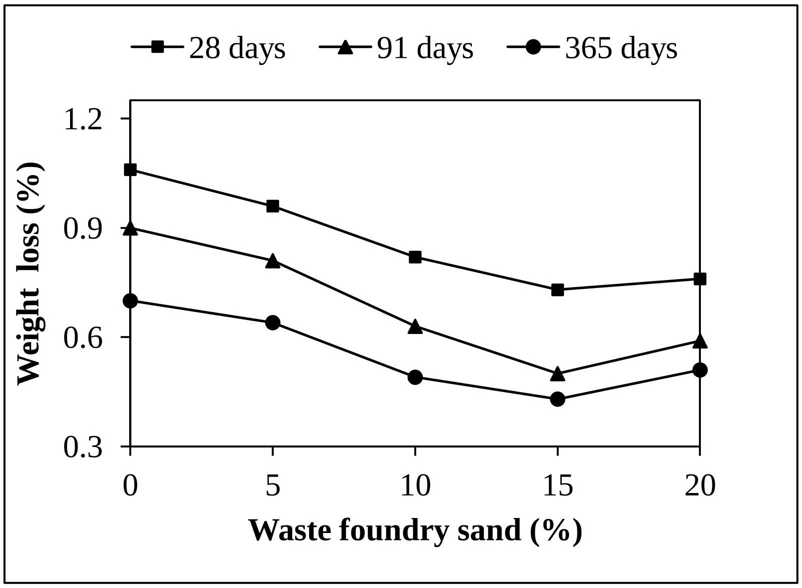


Fig. 4.34: Weight Loss verses Waste Foundry Sand

At the age of 28 days, percentage mass loss of 1.06%, 0.96%, 0.82%, 0.73% and 0.76% were observed for mixes M-6(0%WFS), M-7(5%WFS), M8(10%WFS), M-9(15%WFS) and M-10(20%WFS), respectively. Similarly at the age of 91 days, the percentage loss of mass of scaling residue was found to be 0.90% for M-6, 0.81% for mix M-7, 0.63% for mix M-8, 0.50% for mix M-9 and 0.59% for mix M-5. Concrete mixes M-6, M-7, M-8, M-9 and M-10 exhibited 0.79%, 0.70%, 0.57%, 0.50% and 0.55% mass loss at the age of 365 days. From the above discussion, it is found that, mix M-9(15%WFS) is stronger than all other mix because it gives better resistance against effect of deicing chemical.

Effect of age on deicing salt scaling resistance

Effect of age on scaling resistance of concrete mixes at the age of 28, 91 and 365 day is shown in Fig 4.35. Scaling resistance of all concrete mixes increased with the increase in age. Weight loss was observed as 1.06% at 28 days, 0.90 at 91 days and 0.70% at 365 days for mix M-6(0%WFS). For mix M-7(5%WFS), percentage mass loss was 0.99%, 0.85% and 0.70% at the age of 28, 91 and 365 day. Similarly mass loss was observed 0.82%, 0.63% and 0.49% for mix

M-8(10%WFS); 0.73%, 0.50% and 0.43% for mix M-9(15%WFS); 0.76%, 0.59% and 0.51% for mix M-10(20%WFS) at the age of 28, 91 and 365 day. Maximum resistance against deicing chemical was found at 15% replacement of fine sand with WFS.

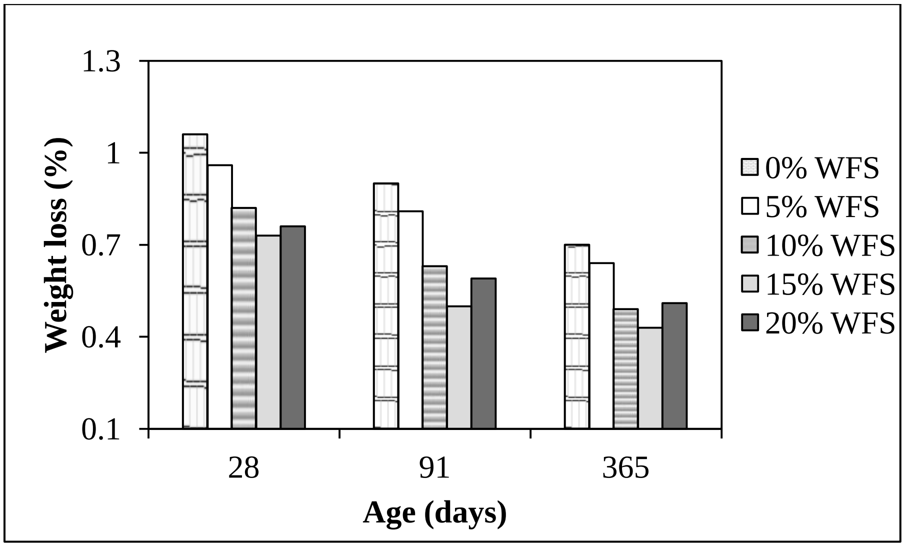


Fig. 4.35: Weight Loss verses Age

Minimum weight loss was observed at 15% WFS content for the both grades of concrete (M20 and M30). With 15% WFS content, concrete mix of both the grades achieved optimum compressive strength and abrasion resistance, and that is possible because of concrete becoming denser with optimum particle packing. Because of this reason, there was minimum weight loss due to deicing salt scaling. Weight loss was slightly increased at 20%WFS content. It is probably due to presence of extra fine particle of WFS in concrete. These fine particles reduced the strength of water cement gel.

Scaling resistance of concrete has very close relationship with abrasion resistance of concrete. At 15% WFS content abrasion resistance is increased in term of wear depth. It means that, concrete surface become harder than other concrete mixes so this harder surface helps to increase the deicing salt scaling resistance of concrete.

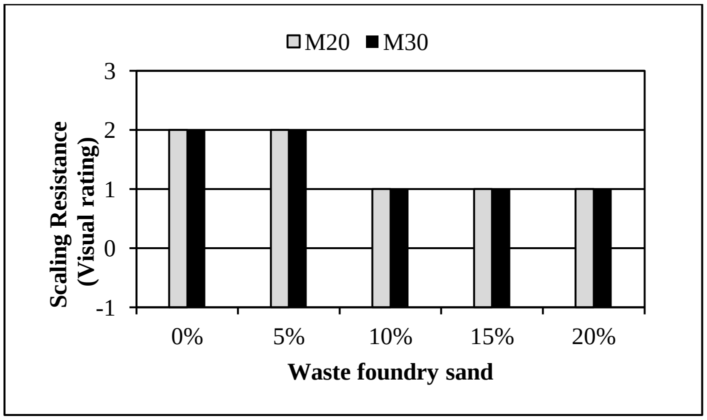
The effect of WFS on deicing salt surface scaling resistance is not available in the literature.

4.7.3 Comparison between M20 and M30 Grade of Concrete

Deicing salt surface scaling resistance was evaluated by visual examination as per ASTM C 672. Scaling resistance is depending upon the surface condition (Given in Table 3.16, Chapter 3). Surface conditions are represented by rating system.

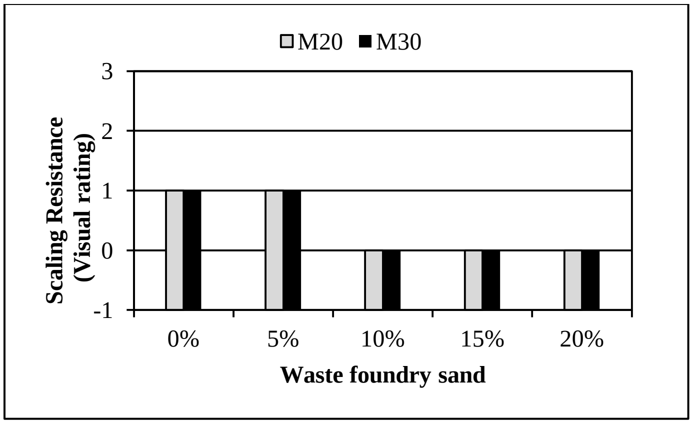
Comparison of Deicing salt surface scaling resistance between the M20 and M30 Grades of concrete mixes are shown in Fig 3.36. It can be seen from this figure that at the age of 28 days, visual rating for mix M-1, M-6 (0%WFS) and M-2, M-7 (5%WFS) were “2”(slight to moderate scaling) whereas other mixes come under rating “1” (very slight scaling). At the age of 91 days, visual rating for mixes M-1, M-2, M-6 and M-7 were “1” whereas visual rating were “0” (no scaling) for mixes M-3, M-4, M-5 (M20 Grade of concrete) and mixes M-8, M-9, M-10 (M30 Grade of concrete). similarly at the age of 365 days, all mix come under rating “0” except mix M-1 and M-6 (0% WFS). It means that with increase in WFS in concrete, scaling resistance of concrete increase. Scaling resistance increases if hardness of concrete surface increases. This same aspect has been reflected by abrasion resistance and rapid chloride permeability of concrete. Very marginal variations were found in scaling residual for M20 and M30 Grades of concrete mixes.

(28 days)



(a)

(91 days)



(365 days)

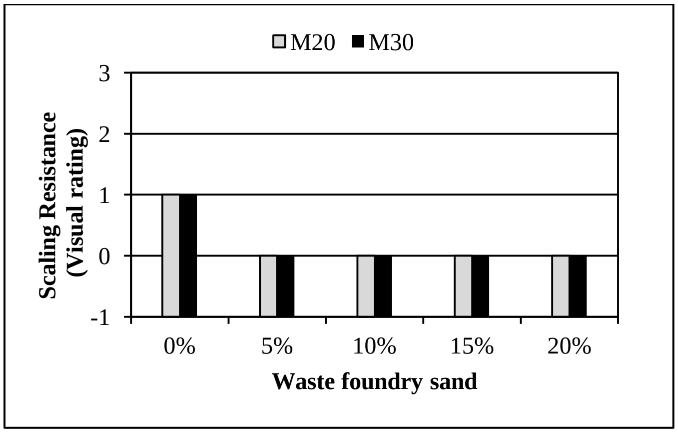


Fig. 4.36: Scaling Resistance (SR) verses WFS at 28, 91 and 365 Days

4.8 ULTRA SONIC PULSE VELOCITY (USPV)

Ultrasonic pulse velocity (USPV) test basically involve the measurement of electronic wave velocity through concrete. This test is used to diagnose the quality of concrete in term of uniformity, determination of cracking and honey-combing, strength, estimation and assessment of concrete deterioration

4.8.1 Ultra Sonic Pulse Velocity of M20 Grade (30Mpa) Concrete

Effect of WFS on USPV of concrete

Effect of WFS and age on ultrasonic pulse velocity of concrete mixes is shown in Fig.4.37 and 4.38. USPV value increased with the increase in waste foundry content in concrete mixes and it also increased with age. The test was carried out at the age of 28, 91 and 365 day.

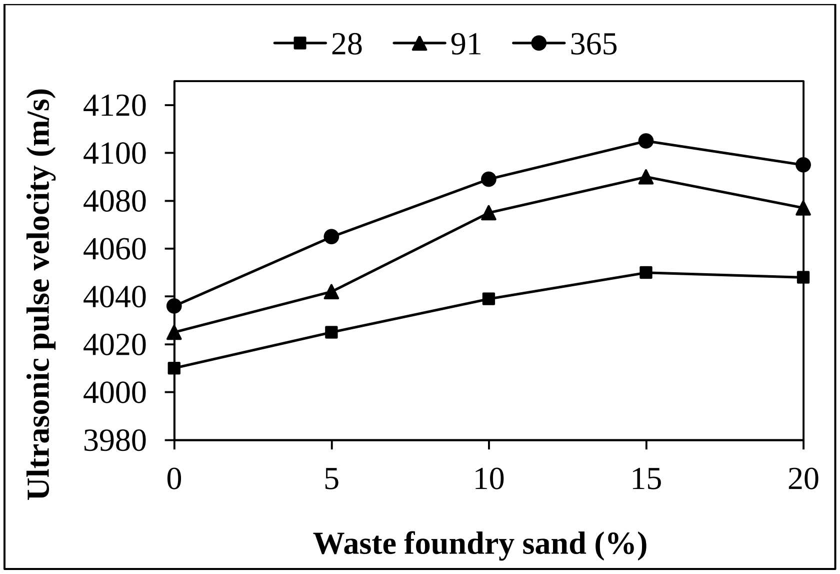


Fig 4.37: Ultrasonic Pulse Velocity verses Waste Foundry Sand

At the age of 28 day, velocity measured for mix M-1(0%WFS) was 4010m/s. further velocity increased to 4025 m/s for mix M-2(5%WFS), 4039 m/s for mix M-3(10%WFS), 4050 m/s for mix M-4(15%WFS) and 4048 m/s for mix M-5(20%WFS). At the age of 91 day, ultrasonic pulse velocity values for mixes M-1, M-2, M-3, M-4 and M-5 was 4025, 4042, 4075, 4090 and 4077 m/s respectively. similarly at the age of 365 day, USPV for concrete mixes M-1, M-2, M-3, M-4 and M-5 computed as 4036, 4065, 4089, 4105 and 4095 m/s respectively. Maximum value of USPV was observed for mix M-4(15%WFS). It increased to 0.99% at 28 days, 1.99% at 91 days and 2.36% at 365days when compare to 28 days USPV for mix M-1(0%WFS).

Effect of age on USPV of concrete

USPV was also increased with an increase of age of curing (shown in Fig. 3.38). It can be seen that maximum increase was observed at 15% WFS. USPV increased from 4010m/s (M-1 at 28 days) to 4105 m/s (M-4 at 365 days). It increased with the difference of 95 M/s. Percentage increase was observed 0.37% at 91 days and 0.65% at 365 days for mix M-1(0%WFS). For mix M-2(5%WFS), USPV increased by 0.42% and 0.9% at the age of 28 and 91 days. Similar percentage gain was observed for mix M-3(10%WFS), M-4(15%WFS) and M-5(20%WFS). It increased in between 0.89% to 1.35%.

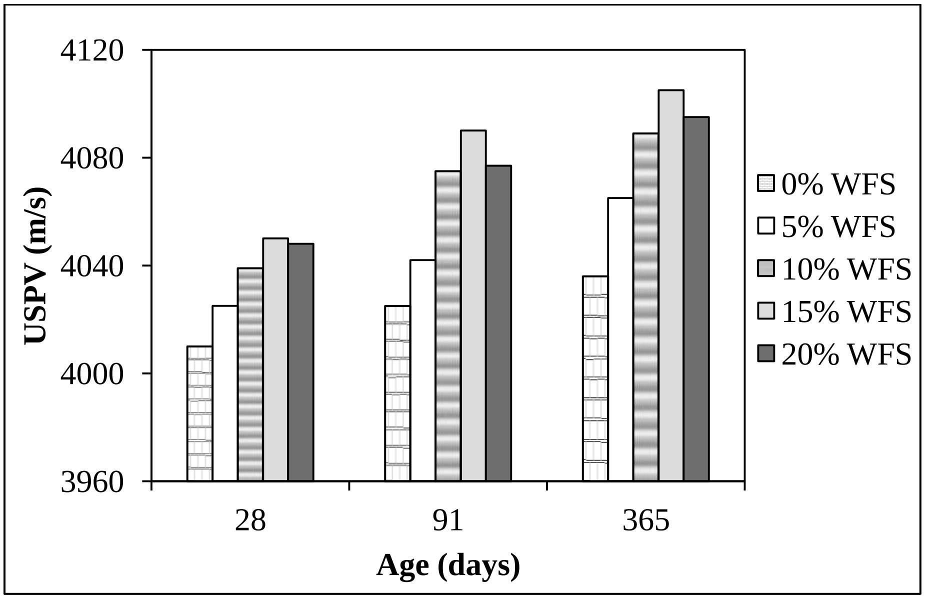


Fig 4.38: Ultrasonic Pulse Velocity verses Age

4.8.2 Ultrasonic Pulse Velocity of M30 Grade (40MPa) Concrete

Effect of WFS on USPV of concrete

Fig. 4.39 shows the effect of WFS on ultra sonic pulse velocity of M30 Grade of concrete. The detail effect of WFS on USPV is explained below.

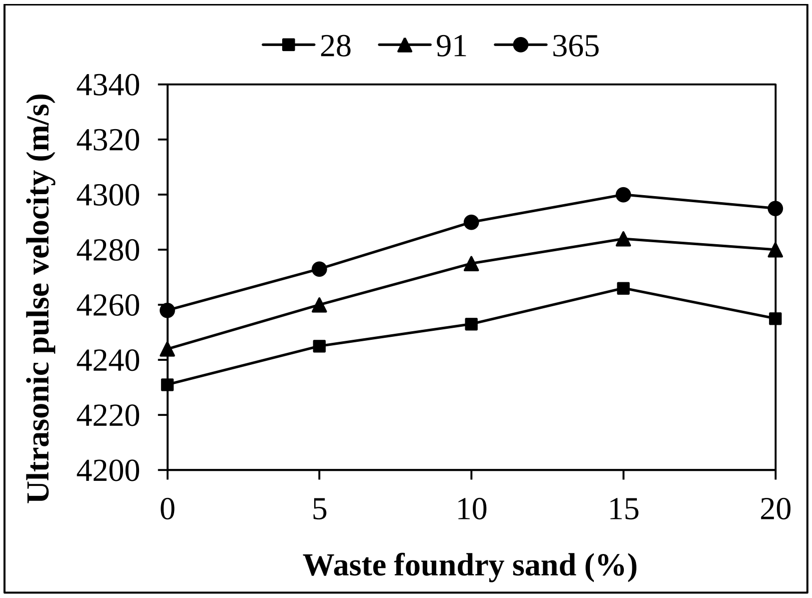


Fig 4.39: Ultrasonic pulse velocity verses Waste Foundry sand

In case of control mix M-6(0%WFS), USPV was around 4231 m/s at the age of 28 days. But an increase was observed after inclusion of WFS in concrete. It increased by 4245 m/s for mix M-7(5%WFS), 4253 m/s for mix M-8(10%WFS), 4266 m/s for mix M-9(15%WFS) and 4255 m/s for mix M-10(20%WFS). Slightly decrease was observed at 20% WFS content but still it remain more than mixes M-6, M-7 and M-8. Similar trend was observed at the age of 91 days. USPV increased from 4244 m/s (M-6) to 4284 m/s (M-9) but for mix M-10(20%WFS), it decreased to 4280 m/s. At the age of 365 days, USPV for mixes M-6, M-7, M-8, M-9 and M-10 computed as 4258, 4273, 4290, 4300 and 4295m/s. maximum value of USPV was observed for mix M-9(15%WFS).

Effect of age on USPV of concrete

Effect of age on USPV of concrete mixes made with and without waste foundry sand is shown in Fig 4.40. As it can be seen in figure that, at the age of 28 days, USPV for mix M-6(0%WFS) was 4231 m/s. due to increase in age, it increased to 4244 m/s at 91 days and 4258 m/s at 365 days. Very less difference (27 m/s) was observed from 28 days to 365 days. Similar trend was observed for mix M-7(5%WFS), M-8(10%WFS), M-9(15%WFS) and M-10(20%WFS). For mix M-7, 0.35% and 0.65 % increase was counted at the age of 91 and 365 days than 28 days USPV (4245 m/s). Percentage increase in USPV of mix M-8(10% WFS) was 0.52 and 0.87% at 91 and 365 days respectively when compared with 28 days USPV value of mix M-8 (4253 m/s). Concrete mix M-9(15% WFS) achieved an increase of 0.42% and 0.8% at the age of 91 and 365 days respectively than 28 days USPV (4266m/s). Similarly, USPV value of mix M-10(20% WFS) was 4255m/s at 28 days. It was increased by 0.58 (91 days) and 0.9% (365 days).

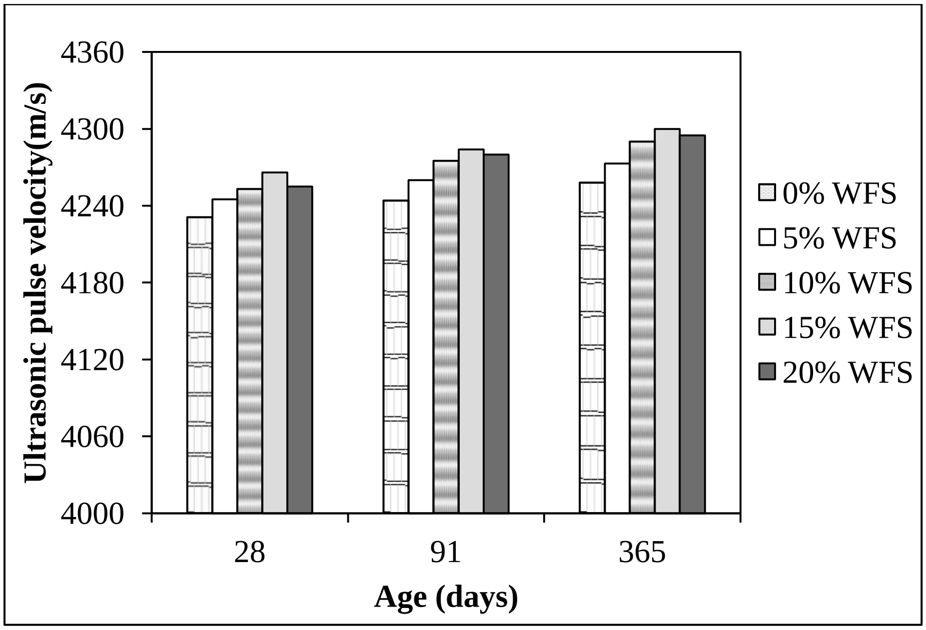


Fig. 4.40: Ultrasonic Pulse Velocity verses Age

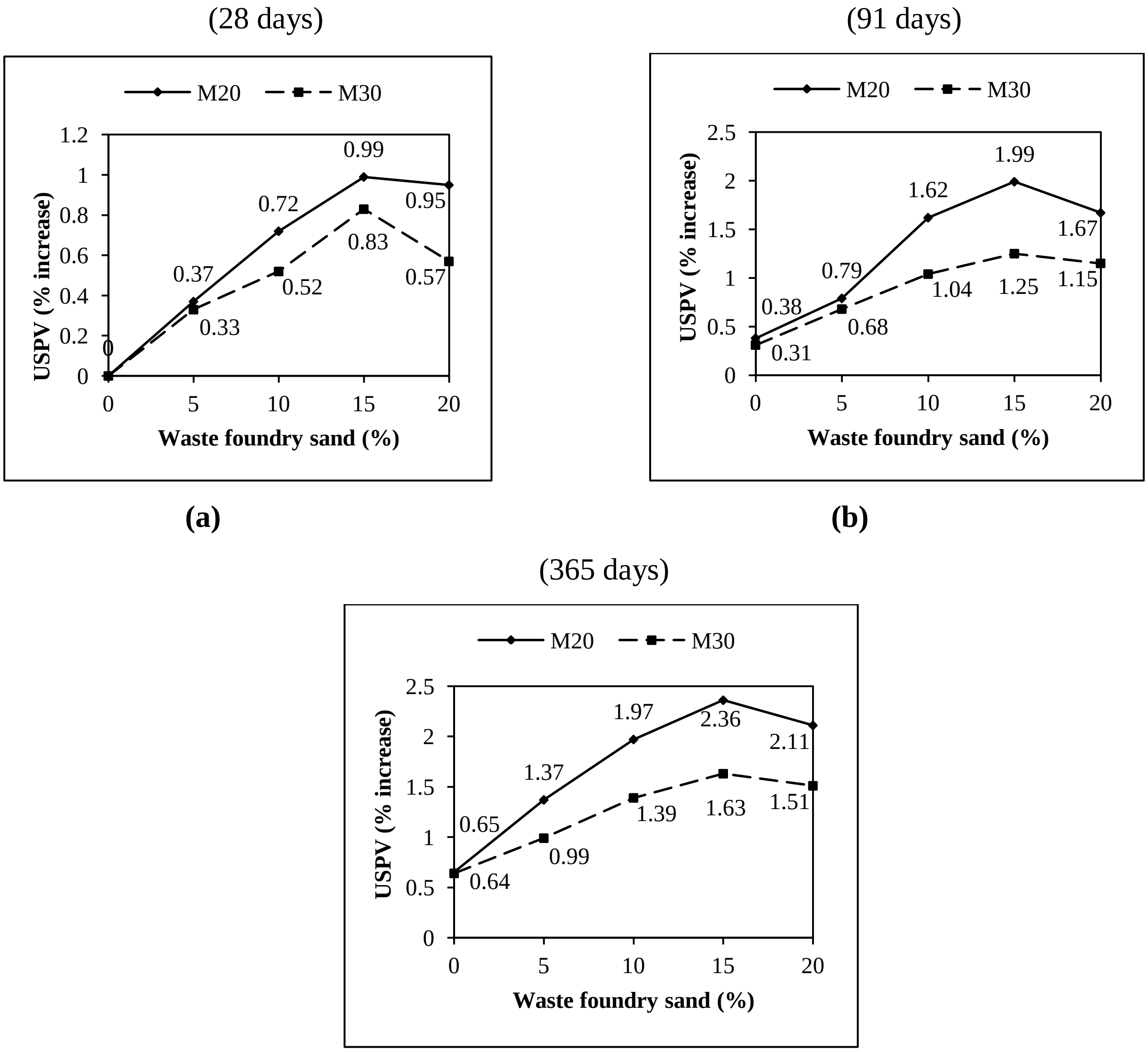
Concrete mixes of both grades of concrete exhibited same trend with inclusion of waste foundry sand at the age of 28, 91 and 365 days. Value of ultrasonic pulse for all mixes of M20 and M30 Grade of concrete varied from 4010m/s to 4300m/s. According to BIS 13311 (part 1):1992, mixes come under the zone of good quality if USPV value lies between 3500m/s-4500m/s. in present investigation, all mixes were come under the zone of good quality of concrete. It also satisfied ASTM 597-93.

With increase in the percentage of WFS, the ultrasonic pulse velocity increased. This indicate that, the fine particle of waste foundry sand packed between the particle of concrete matrix and become less permeable hence ultrasonic wave took less time to reach the receiving transducer. Thus it decreased the transit time and hence pulse velocity increased.

It means that the quality of concrete in term of density, homogeneity and lack of imperfections is good. Through this investigation, it has been established that up to 15% use of WFS results in better enhanced strength and more durable concrete.

4.8.3 Comparison between M20 and M30 Grades of Concrete

Comparison of ultrasonic pulse velocity (USPV) of M20 and M30 Grades of concrete mixes at the age of 28, 91 and 365 days, is shown in Fig 4.41. Percentage increase was found out to examine the comparison between the concrete grades. Values of percentage increase were calculated in comparison with the 28 days USPV of concrete mixes M-1 and M-6 at 0% WFS replacement. It was found that there was better improvement in USPV for M20 Grade of concrete mixes than M30 Grade of concrete mixes. it means that inclusion of WFS in concrete mixes improve the internal micro structure and increase the densification of matrix for M20 Grade of concrete than M30 Grade of concrete. At the age of 28 days, maximum percentage increase (0.99%) was observed for M20 Grade of concrete at 15% WFS replacement. Similar trend was observed at 91 and 365 days. Values of percentage increase are shown in Fig 4.41.



(a) **(b)**

(c)

Fig. 4.41: Ultrasonic Pulse Velocity verses WFS at 28, 91 and 365 Days

4.9 REBOUND HAMMER

Rebound hammer is used to predict the compressive strength of the concrete. In this research, compressive strength was found out for concrete mixes M-1, M-2, M-3, M-4 and M-5 (M20 Grade concrete) and M-6, M-7, M-8, M-9 and M-10 (M30 Grade concrete) by using rebound hammer. It is not an accurate method. According to BIS: 13311 (part 2)-1992, accuracy of prediction of concrete strength in structure is ± 25 percent. Values of the compressive strength for both grades of concrete are given in Table 4.3. 15% error was found at 28 days compressive strength of control mix M-1 (0%WFS) when compared with the 30MPa (28 days destructive strength of control mix). Similar trend was observed in M30 Grade concrete. Destructive strength control mix M-6 (0%WFS) was 40 MPa. Compressive strength of 36 MPa was found by rebound hammer. The error was 9%. Due to inclusion of waste foundry sand content in concrete, the compressive strength was observed higher than that of control one. It was also found that compressive strength was increased with age (91days and 365 days) in both grades of concrete.

Table 4.3 Compressive Strength (MPa) by Rebound Hammer

M20 Grade of Concrete (MPa)					**M30 Grade of Concrete (MPa)**				
Mix	**WFS (%)**	**28 days**	**91 days**	**365 days**	**Mix**	**WFS (%)**	**28 days**	**91 days**	**365 days**
M-1	0	25.5	29.1	33.6	M-6	0	36.2	38	42.6
M-2	5	28.4	35.5	37.2	M-7	5	37.1	41.5	45
M-3	10	33.4	37	38.5	M-8	10	41.5	43.2	47.9
M-4	15	33.5	37.4	41	M-9	15	42.7	45.1	49.4
M-5	20	32	36.5	38	M-10	20	42	44.2	48.8

4.10. STATISTICAL ANALYSIS OF THE RESULTS

4.10.1 Statistical Analysis of M20 Grade (30 MPa) Concrete

The correlation analysis was carried out between compressive strength, splitting tensile strength, MOE, ultrasonic pulse velocity, abrasion resistance, scaling resistance and rapid chloride permeability of concrete. It was observed that there is good correlation between these properties. A polynomial relationship in the form of $y = ax^2+bx+c$ seems to best fit the data with R^2 values.

The regression equations and value of correlation coefficient R^2 between strength properties are given in Table 4.4 and shown in Figs 4.42 to 4.47. As evident from these results that value of correlation coefficient is varied from 0.8957 to 0.9775. The high values of correlation coefficient indicate that there is strong relationship between various properties of concrete. Coefficient of correlation amongst strength properties (compressive strength, splitting tensile strength and modulus of elasticity) is very high (from 0.9584 to 0.9775). These strength properties also have a very strong relation with ultrasonic pulse velocity (USPV). It means that, inclusion of WFS in concrete gives better affect to its strength properties. It makes the matrix dense due to its particle fineness. Due to this, the quality of concrete in term of its density, homogeneity and lack of imperfections improved.

Table 4.4 Regression Analysis between Strength Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Compressive Strength verses Splitting Tensile Strength	$y = -0.0018x^2 + 0.2157x - 1.6301$	0.9775
Compressive Strength verses Modulus of Elasticity	$y = 0.0006x^2 + 0.23x + 15.635$	0.9606
Splitting Tensile Strength verses Modulus of Elasticity	$y = 0.7168x^2 - 1.9039x + 21.746$	0.9584
Compressive Strength verses USPV	$y = 0.2049x^2 - 8.6701x + 4082.7$	0.9635
Splitting Tensile Strength verses USPV	$y = 68.32x^2 - 435.3x + 4703.5$	0.9067
Modulus of Elasticity verses USPV	$y = -3.8682x^2 + 222.87x + 894.08$	0.8957

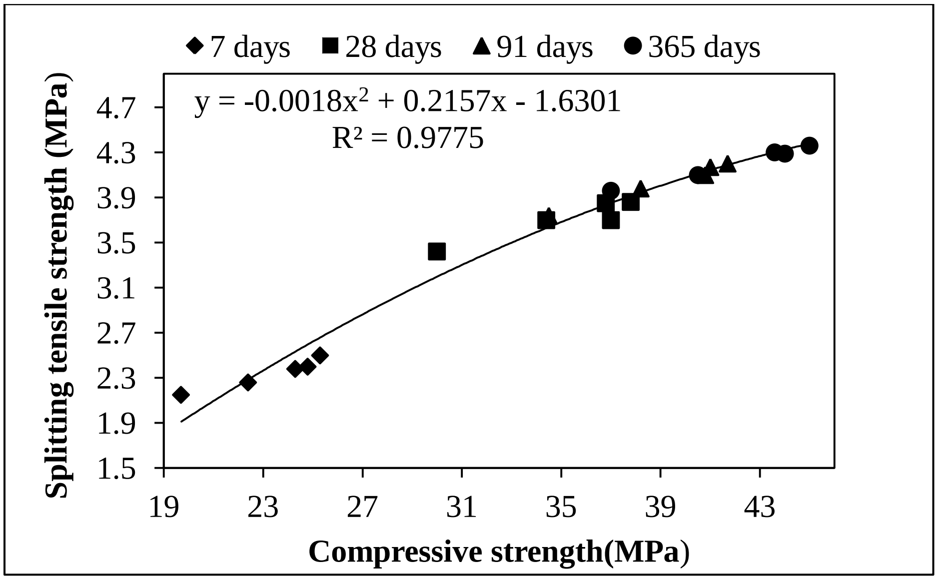


Fig. 4.42: Compressive Strength verses Splitting Tensile Strength

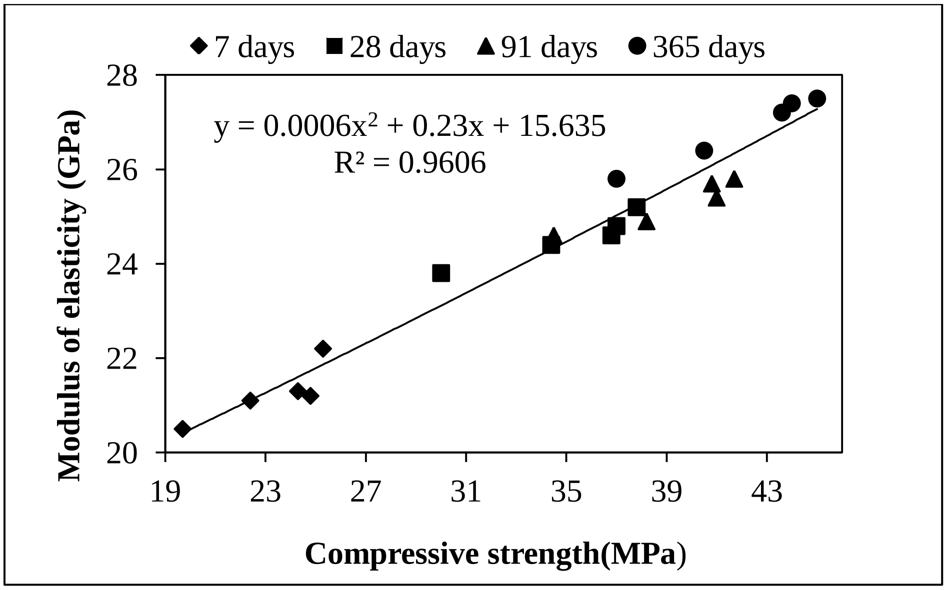


Fig. 4.43: Compressive Strength verses Modulus of Elasticity

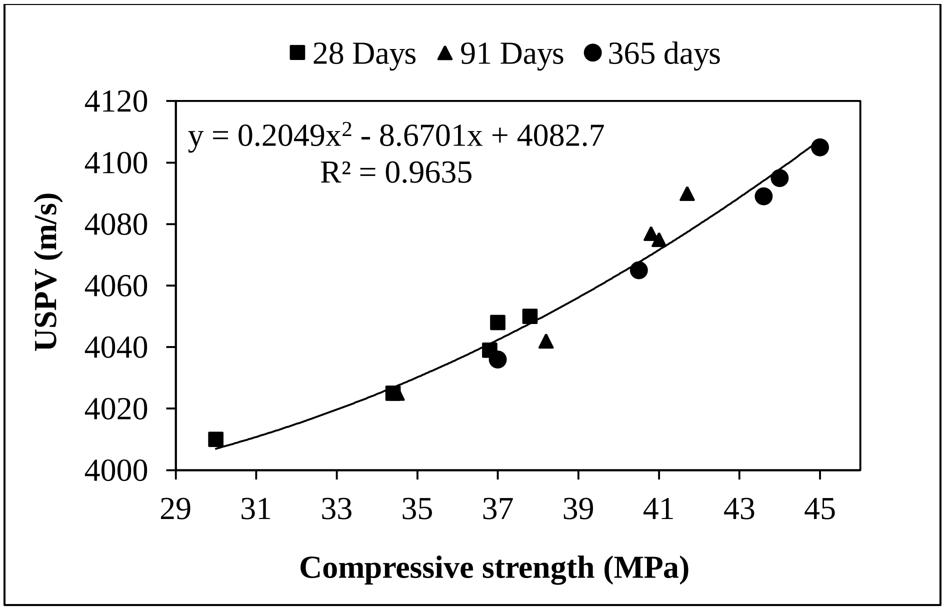


Fig. 4.44: Compressive Strength verses USPV

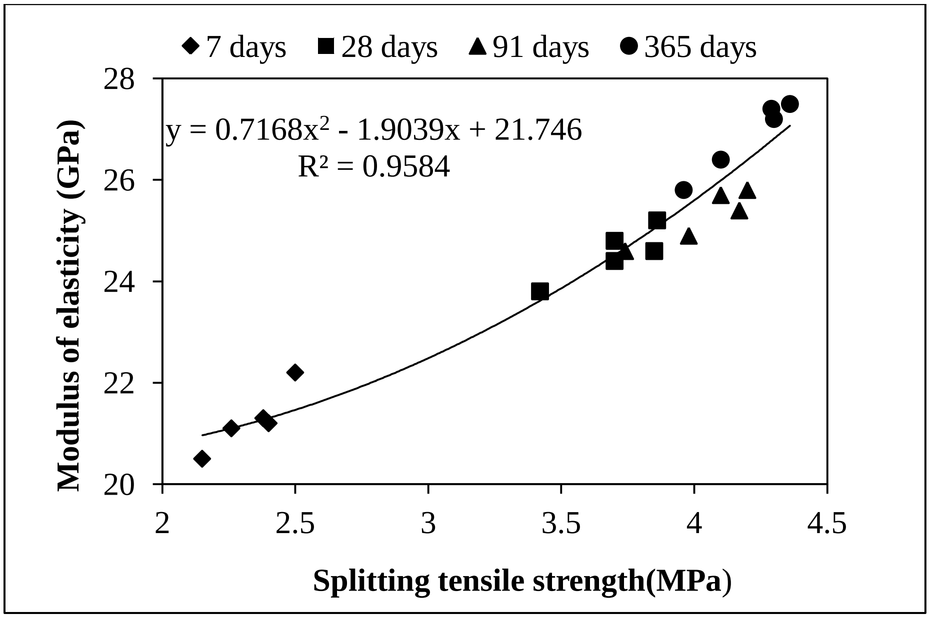


Fig. 4.45: Splitting Tensile Strength verses Modulus of Elasticity

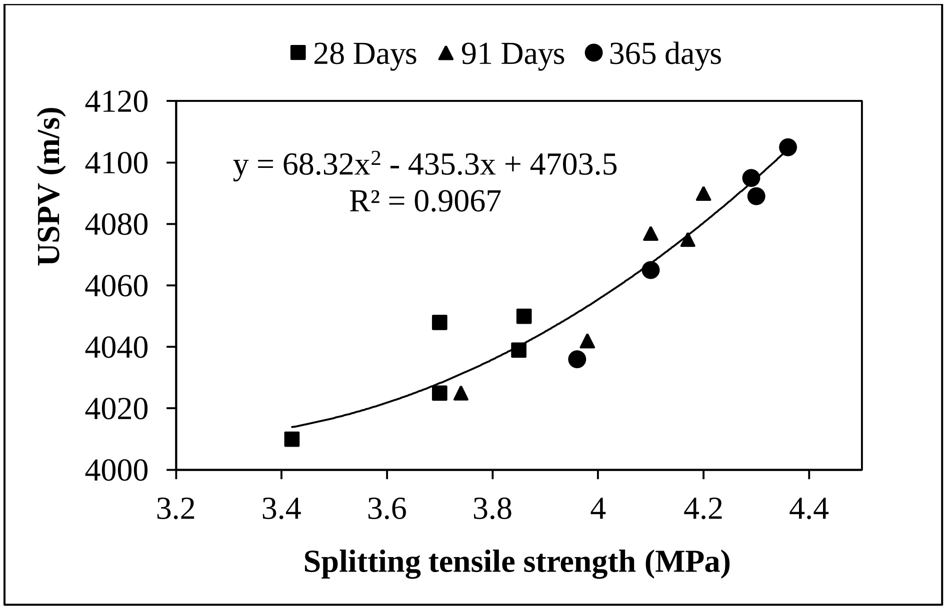


Fig. 4.46: Splitting Tensile Strength verses USPV

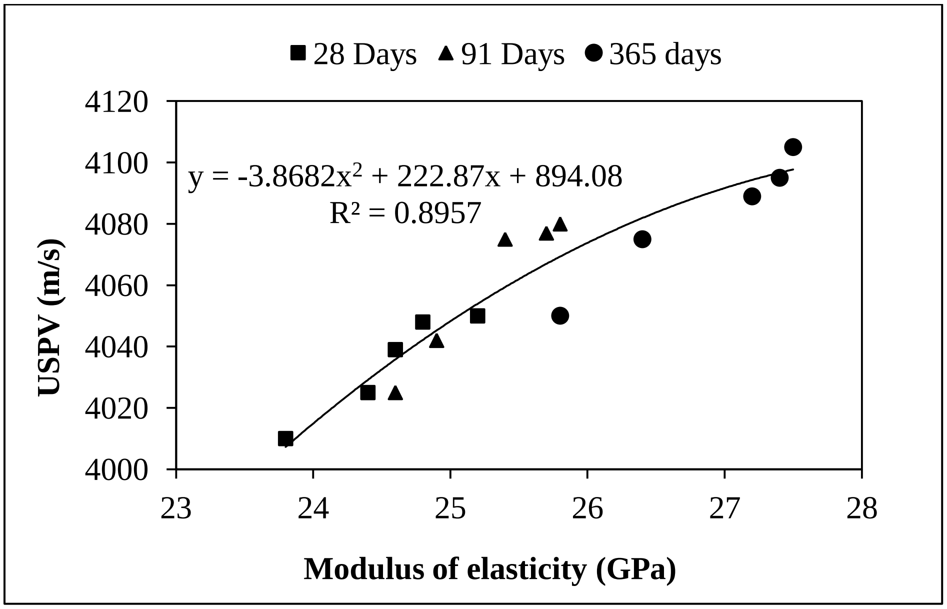


Fig. 4.47: Modulus of Elasticity verses USPV

Regression analysis was made to establish a general relationship between durability properties (abrasion resistance, rapid chloride permeability and deicing salt scaling resistance) is given in Table 4.5, and shown in Figs. 4.48 to 4.53 with the best fit established.

Table 4.5: Regression Analysis between Durability Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Abrasion Resistance verses RCPT	$y = -25.583x^2 + 654.38x - 182.76$	0.9629
Abrasion Resistance verses Scaling Resistance	$y = 0.0243x^2 + 0.4421x - 0.4238$	0.9695
RCPT verses Scaling Resistance	$y = 4E-07x^2 + 5E-05x + 0.0963$	0.9626
Abrasion Resistance verses USPV	$y = 16.368x^2 - 171.72x + 4370.4$	0.9458
Scaling Resistance verses USPV	$y = 2E-05x^2 - 0.1341x + 284.6$	0.9693
RCPT verses USPV	$y = 0.0095x^2 - 82.233x + 179049$	0.9274

Value of correlation coefficient varied from 0.9274 to 0.9695. Correlation coefficient value was near to one. It means that, inclusion of WFS in concrete gives the significant influence to durability properties. Finer particle of WFS filled the voids of concrete matrix and become concrete surface harder and less permeable than control one. It decreased the wear depth and chloride penetrability. Due to harder surface, deicing salt scaling resistance of concrete increased. Higher values of correlation coefficient indicate that depth of wear has a strong relationship with chloride penetrability, scaling resistance and USPV.

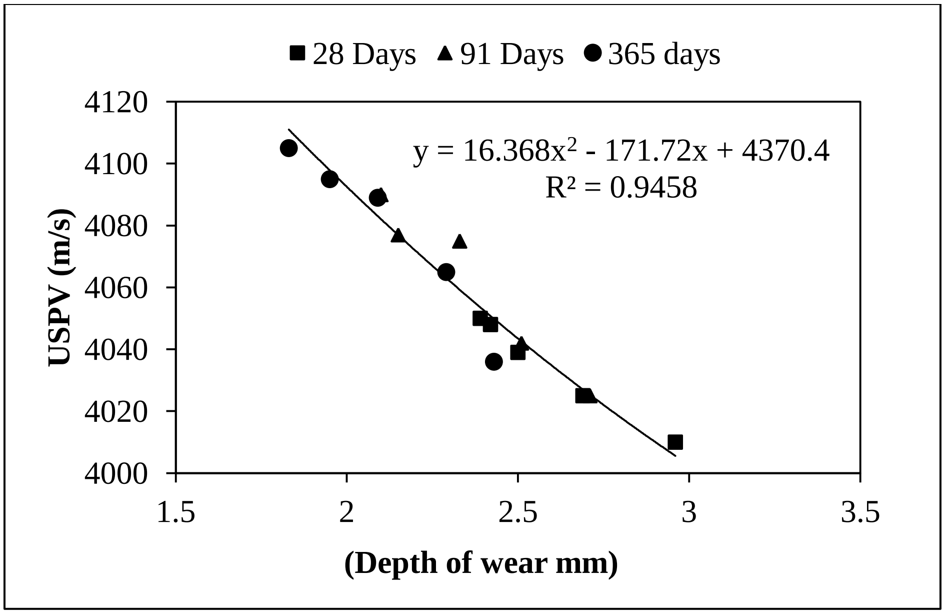


Fig. 4.48: **Abrasion Resistance verses Ultrasonic Pulse Velocity**

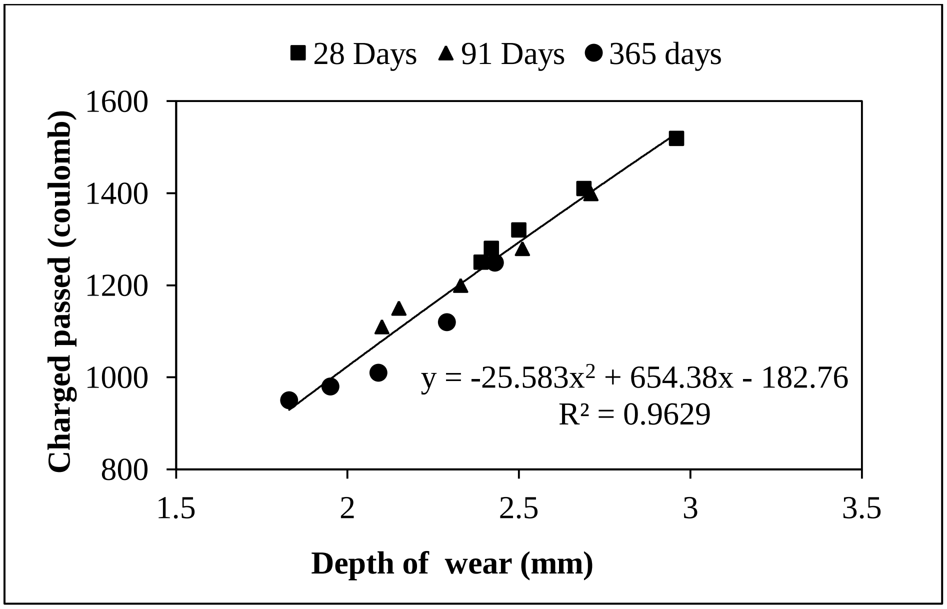


Fig. 4.49: Abrasion Resistance verses RCPT

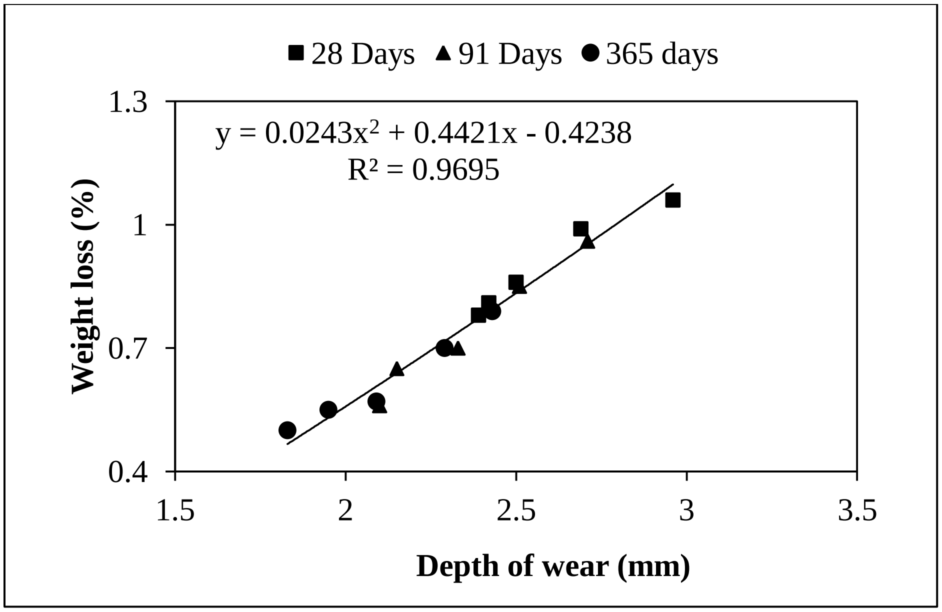


Fig. 4.50: Abrasion Resistance verses Scaling Resistance

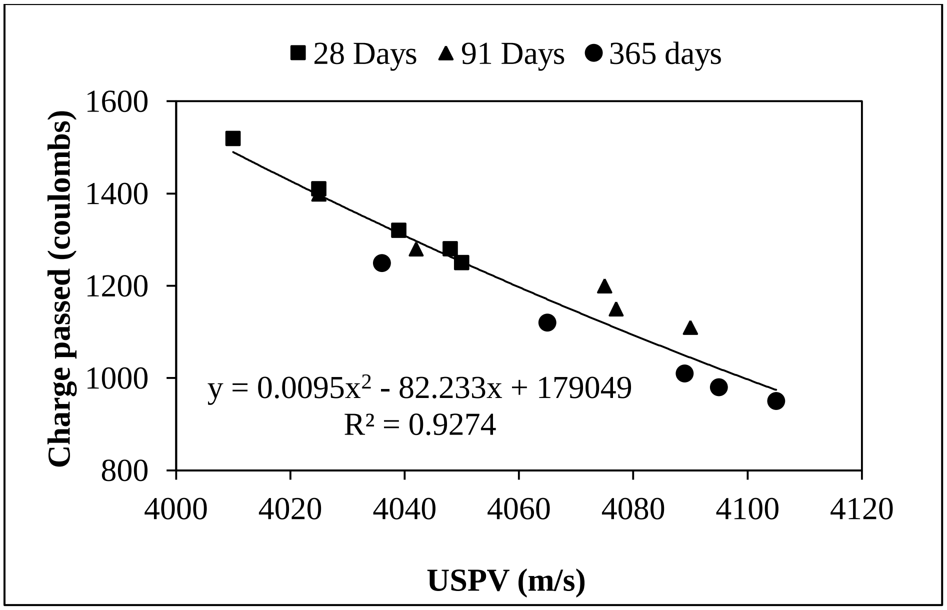


Fig. 4.51: Ultrasonic Pulse Velocity verses RCPT

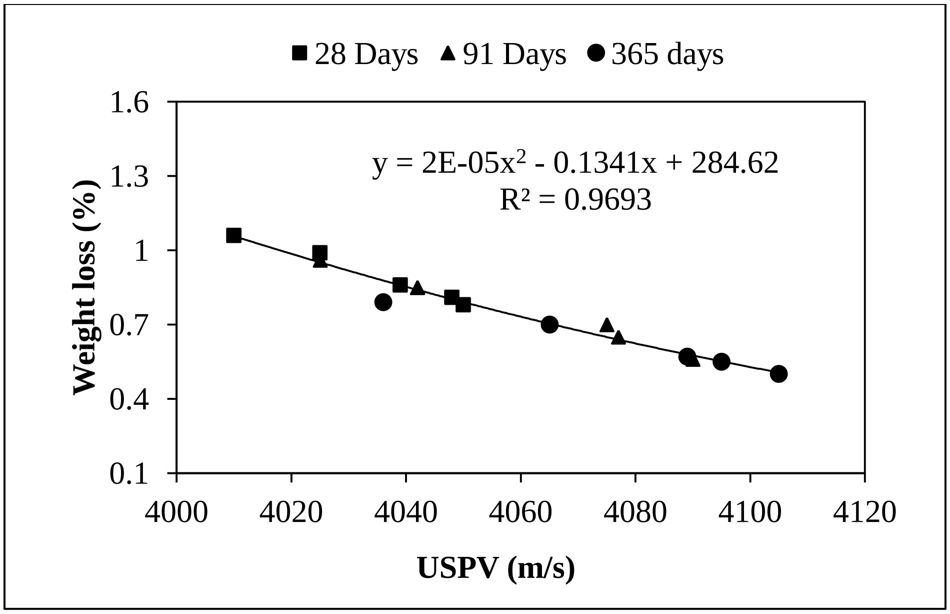


Fig. 4.52: **Ultrasonic Pulse Velocity verses Scaling Resistance**

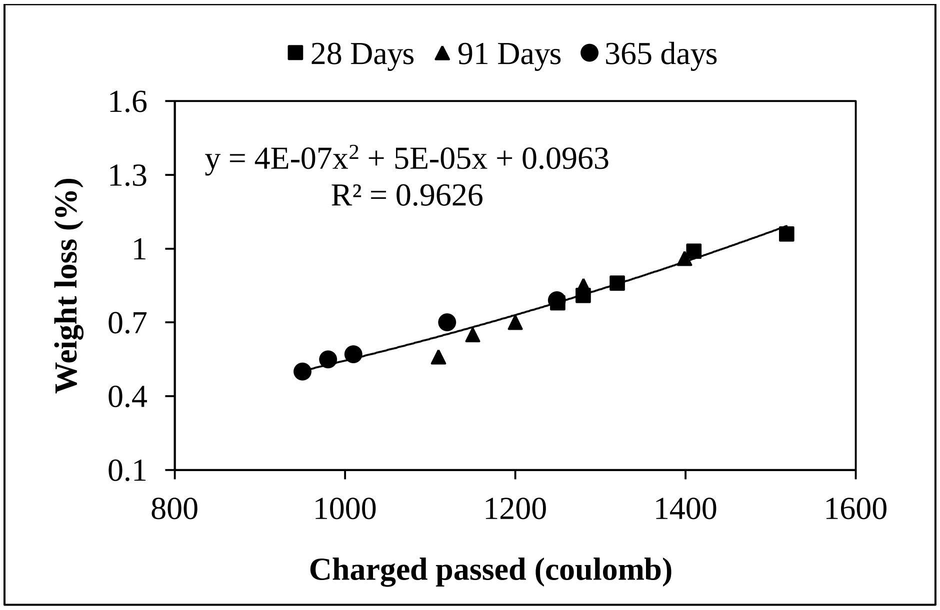


Fig. 4.53: RCPT verses Scaling Resistance

A regression analysis was made to establish a general relationship between strength and durability properties. The analysis was carried out using the overall result data.

Correlation between the strength properties (compressive strength, splitting tensile strength and modulus of elasticity) and durability properties (abrasion resistance, rapid chloride permeability and deicing salt scaling resistance) is shown in Figs 4.54-4.62. Regression equations and correlation coefficients (R^2) are presented in Table 4.6. Correlation coefficient value varied from 0.949 to 0.9722 for relationship between compressive strength and durability properties. Similarly R^2 value varied 0.8734 to 0.9194 for relationship between splitting tensile strength and durability properties. Relation of modulus of elasticity and durability properties provided R^2 value from 0.8709 to 0.9334. Higher values of coefficient indicate that a strength property has a strong relationship with durability.

It means an increase in compressive strength with inclusion of WFS in concrete leads to a decrease in chloride ion penetrability and improves the quality of concrete. Values of correlation coefficient indicates that depth of wear has a strong relationship with strength properties (compressive and splitting tensile and well as modulus of elasticity). Generally, an increase in strength and modulus of elasticity lead to an increase in abrasion resistance of the concrete.

Table 4.6 Regression Analysis between Strength and Durability Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Compressive Strength verses RCPT	$y = -0.8108x^2 + 22.478x + 1577.2$	0.9722
Compressive Strength verses Abrasion Resistance	$y = -0.0007x^2 - 0.0171x + 4.1157$	0.9518
Compressive Strength verses Scaling Resistance	$y = -0.0006x^2 + 0.0018x + 1.534$	0.9495
Splitting tensile strength verses RCPT	$y = -248.09x^2 + 1369.3x - 286.93$	0.9194
Splitting tensile strength verses Abrasion Resistance	$y = -0.2722x^2 + 1.0922x + 2.3414$	0.8734
Splitting tensile strength verses Scaling Resistance	$y = -0.2226x^2 + 1.1487x - 0.2738$	0.9019
Modulus of elasticity verses RCPT	$y = 15.246x^2 - 922.79x + 14821$	0.9334
Modulus of elasticity verses Abrasion Resistance	$y = 0.0439x^2 - 2.5069x + 37.733$	0.8709
Modulus of elasticity verses Scaling Resistance	$y = 0.0305x^2 - 1.7112x + 24.532$	0.8752

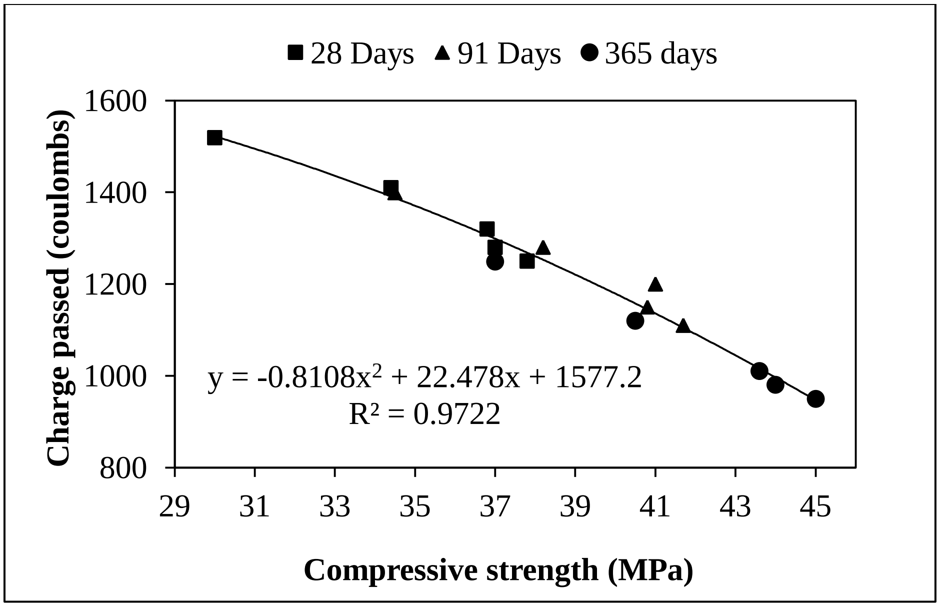


Fig. 4.54: Compressive Strength verses RCPT

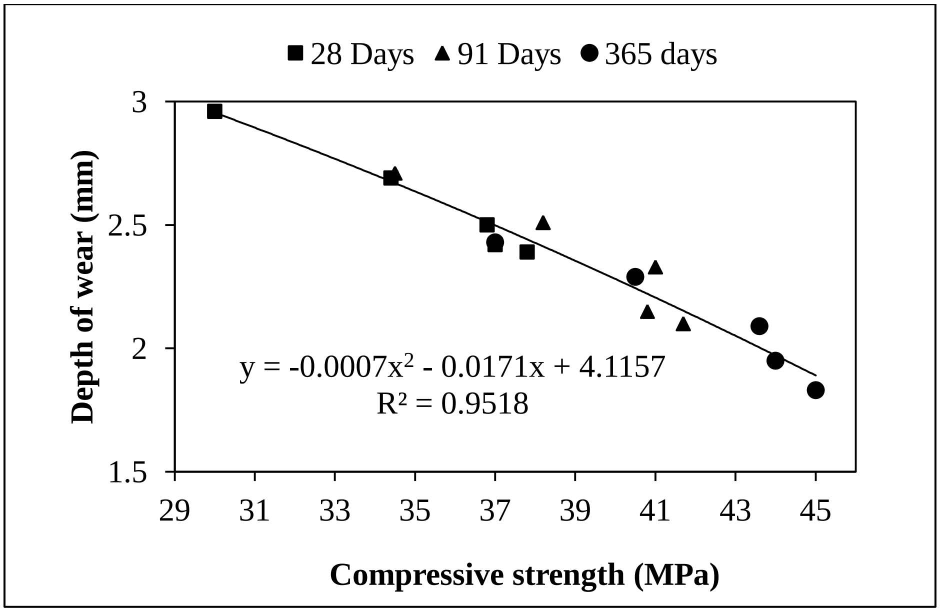


Fig. 4.55: Compressive Strength verses Abrasion Resistance

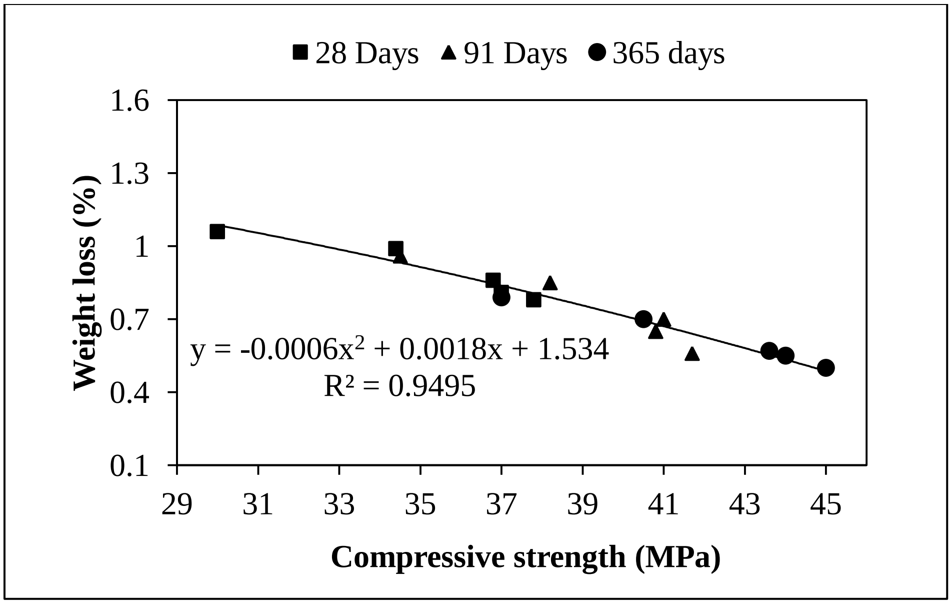


Fig. 4.56: Compressive Strength verses Scaling Resistance

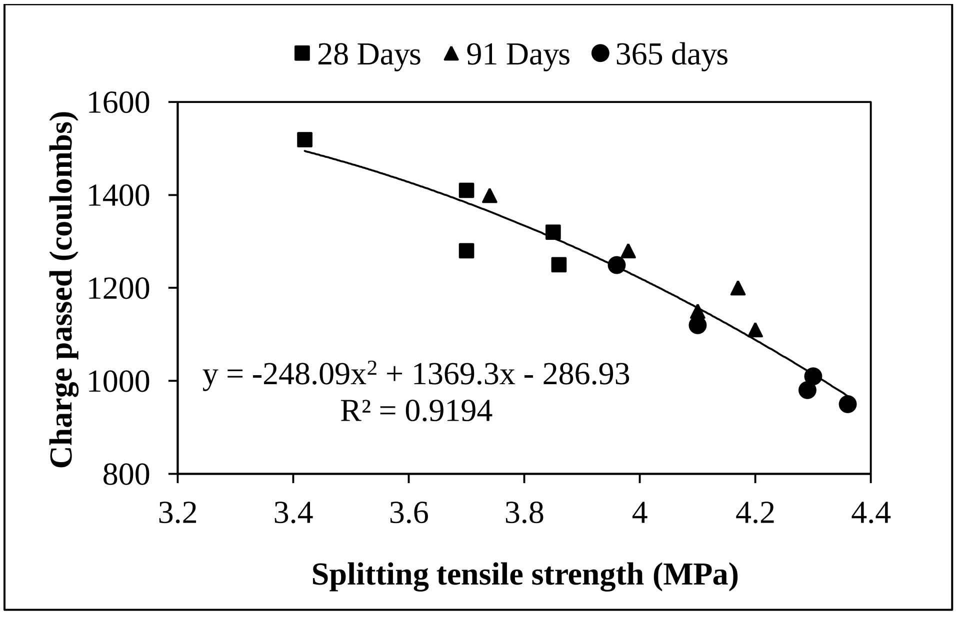


Fig. 4.57: Splitting Tensile Strength verses RCPT

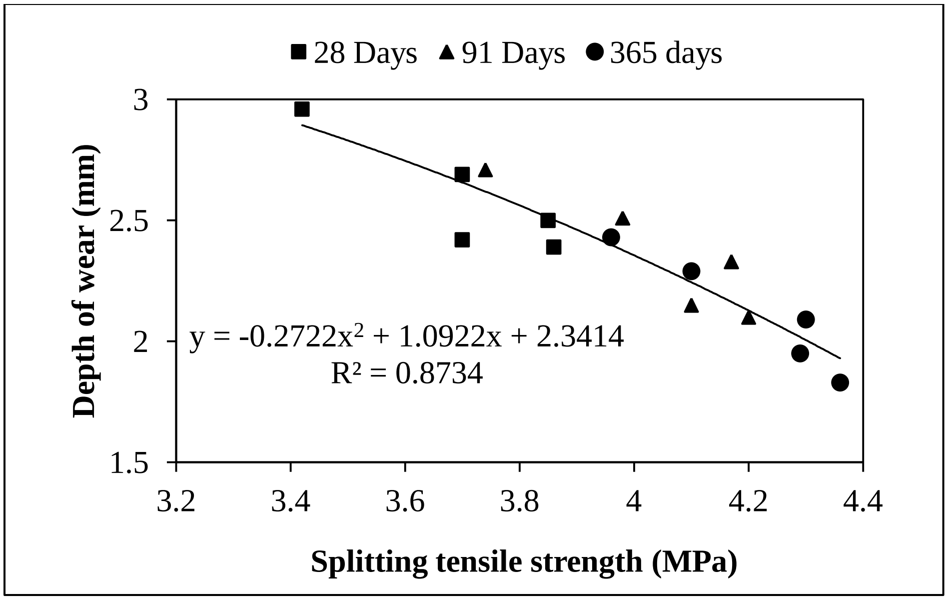


Fig. 4.58: Splitting Tensile Strength verses Abrasion Resistance

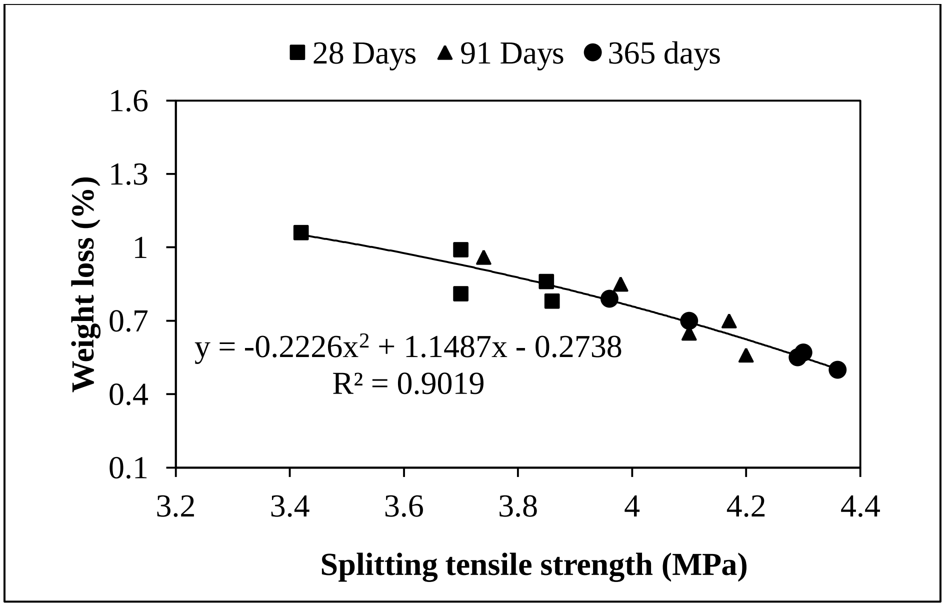


Fig. 4.59: Splitting Tensile Strength verses Scaling Resistance

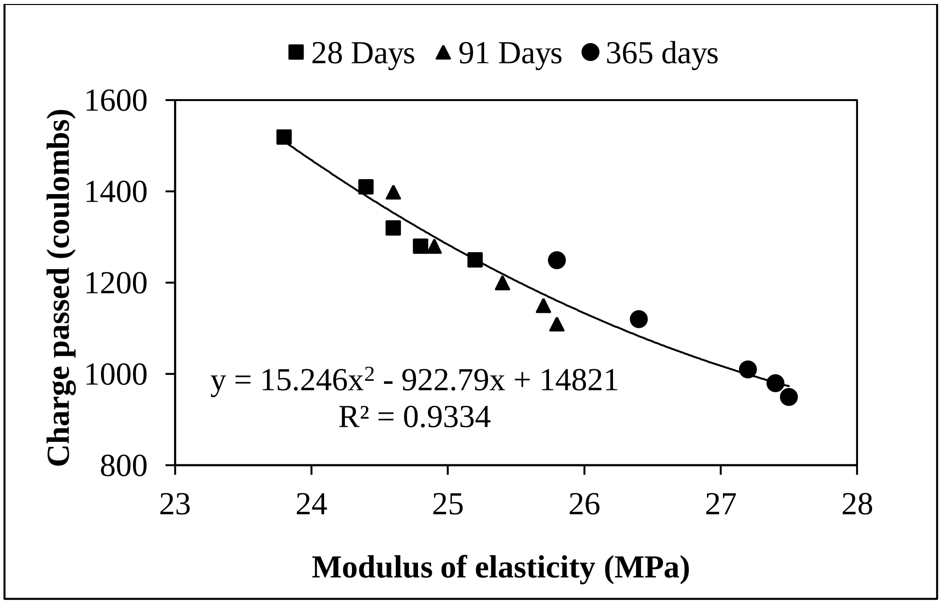


Fig. 4.60: Modulus of Elasticity verses RCPT

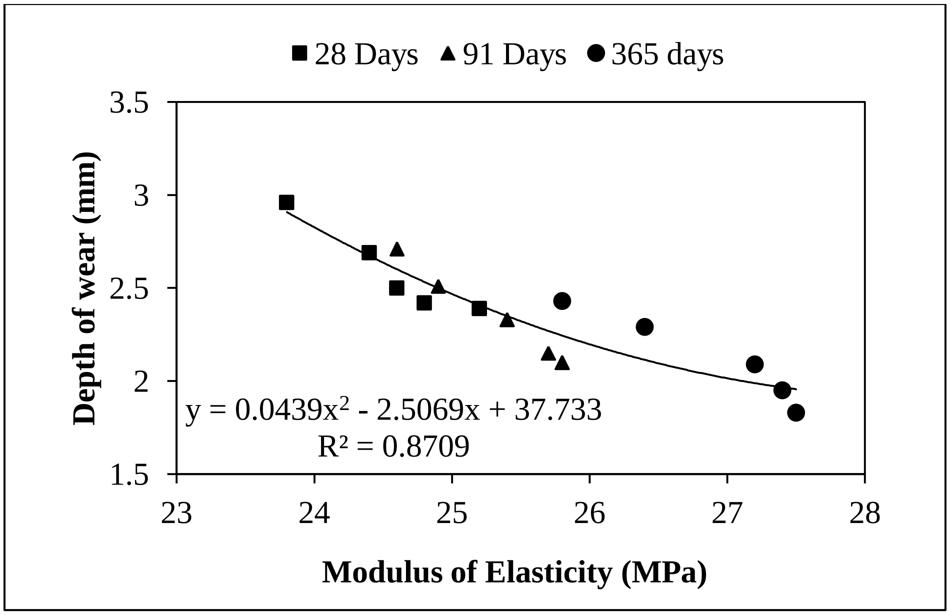


Fig. 4.61: Modulus of Elasticity verses Abrasion Resistance

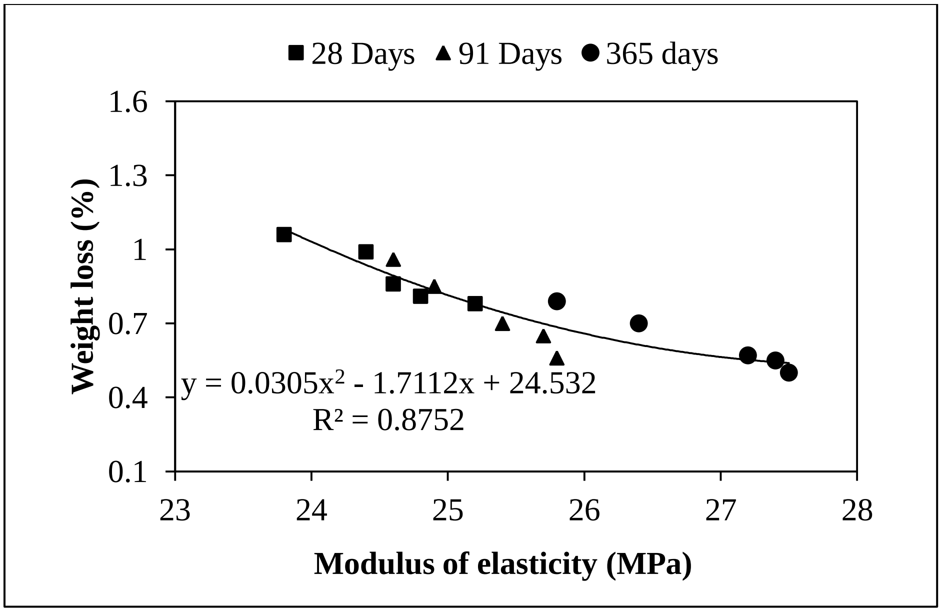


Fig. 4.62: Modulus of Elasticity verses Scaling Resistance

4.10.2 Statistical Analysis of M30 Grade (40 MPa) Concrete

Figs 4.63 to 4.68 show the relationship between the strength properties (compressive strength, splitting tensile strength and modulus of elasticity). Regression analysis was carried out to understand the relationship between the properties. Equation and correlation coefficient are presented in Table 4.7. A polynomial relationship in the form of $y = ax^2+bx+c$ seems to best fit the data with highest R^2 values. Value of correlation coefficient varied from 0.9314 to 0.981. Higher values of correlation coefficient indicate that compressive strength has a strong relationship with splitting tensile strength and modulus of elasticity.

Table 4.7 also presented the relationship between strength properties and USPV. Increase in waste foundry sand content in concrete led to an increase of USPV. It means that quality of concrete increased in term of uniformity and homogeneity. Due to increase in quality of concrete, strength properties was also increased. The above statement is proved by higher values of R^2. This was varied from 0.8750 to 0.9311.

Table 4.7 Regression Analysis between Strength Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Compressive Strength verses Splitting Tensile Strength	$y = -0.0018x^2 + 0.2236x - 1.9345$	0.9787
Compressive Strength verses Modulus of Elasticity	$y = 0.0014x^2 + 0.1838x + 20.215$	0.981
Splitting Tensile Strength verses Modulus of Elasticity	$y = 0.7276x^2 - 2.254x + 26.797$	0.9314
Compressive Strength verses USPV	$y = -0.0929x^2 + 13.788x + 3825.1$	0.9311
Splitting Tensile Strength verses USPV	$y = 13.377x^2 - 38.542x + 4160.1$	0.9055
Modulus of Elasticity verses USPV	$y = -1.1022x^2 + 85.037x + 2678$	0.8750

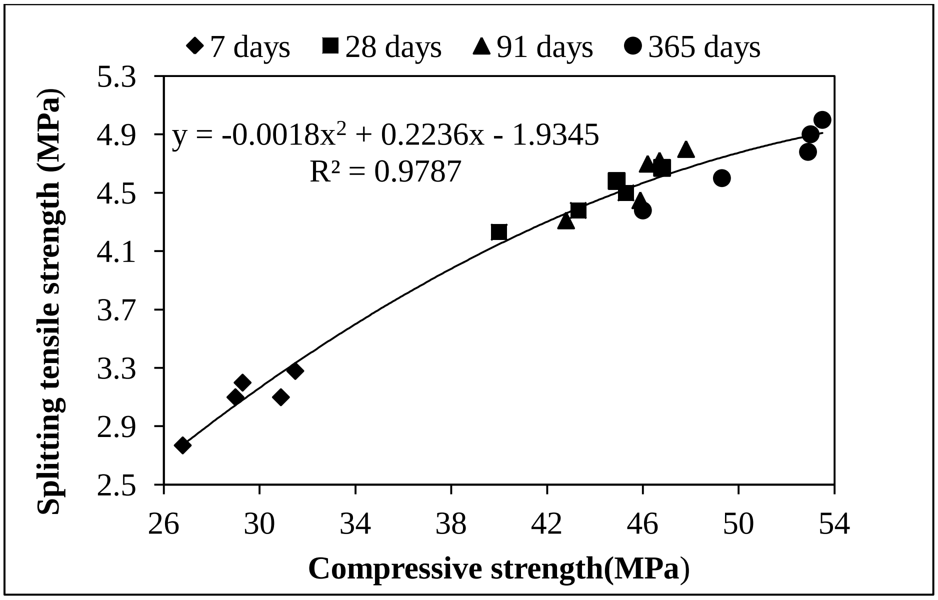


Fig. 4.63: Compressive Strength verses Splitting Tensile Strength

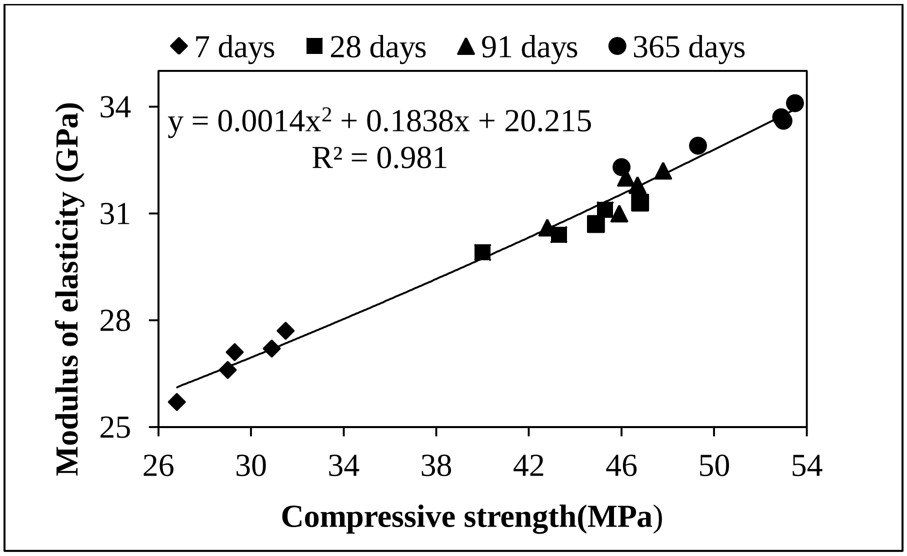


Fig. 4.64: Compressive Strength verses Modulus of Elasticity

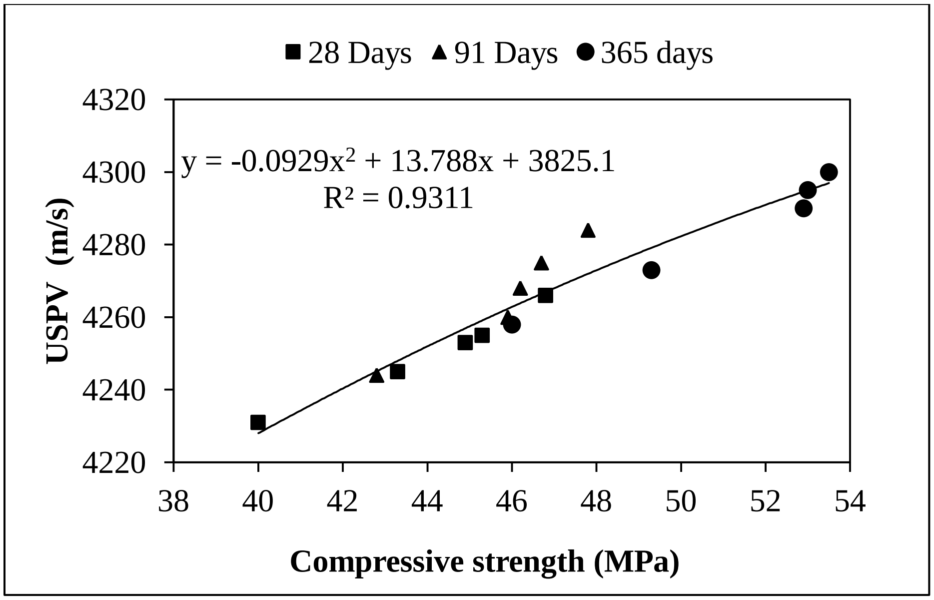


Fig. 4.65: Compressive Strength verses USPV

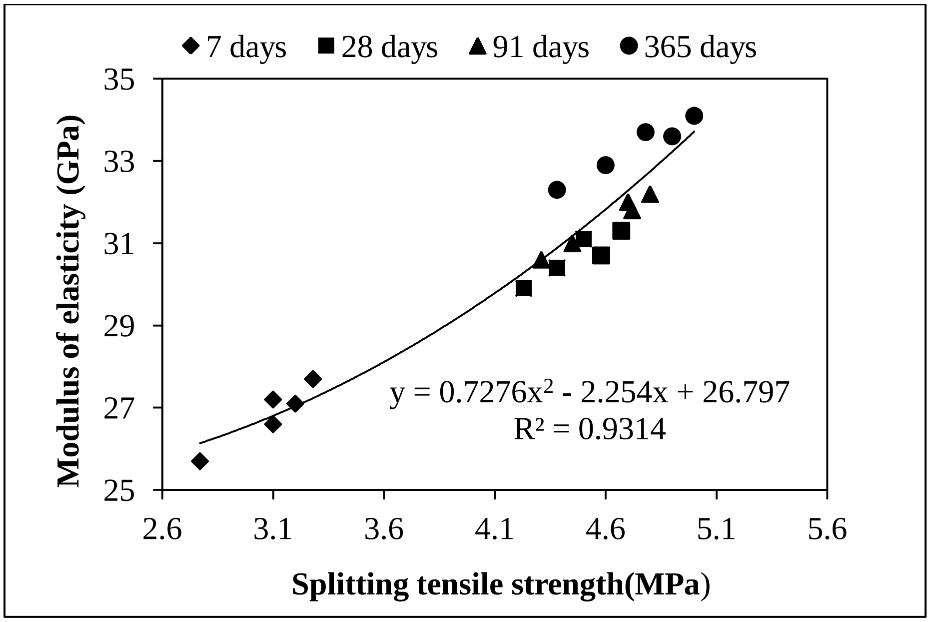


Fig. 4.66: Splitting Tensile Strength verses Modulus of Elasticity

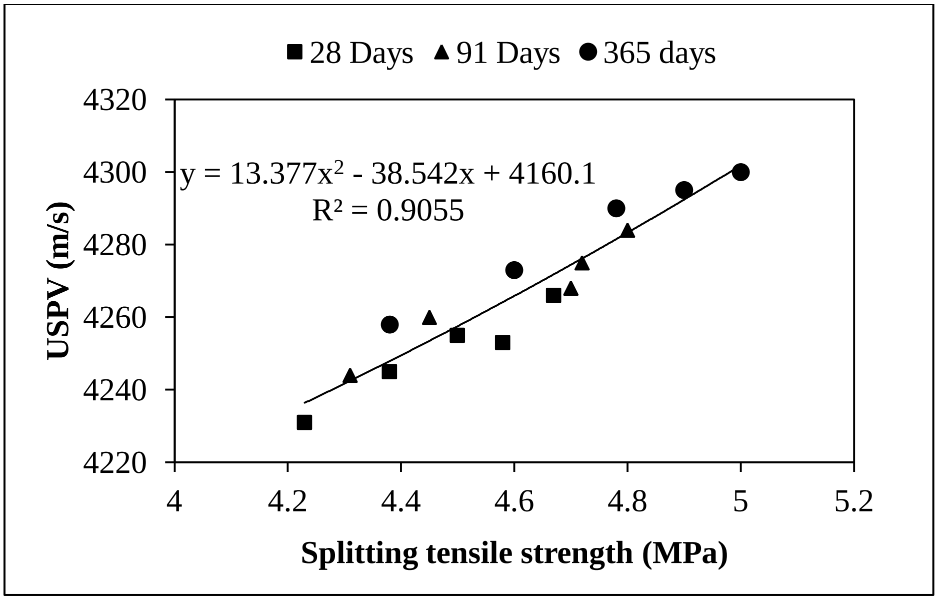


Fig. 4.67: Splitting Tensile Strength verses USPV

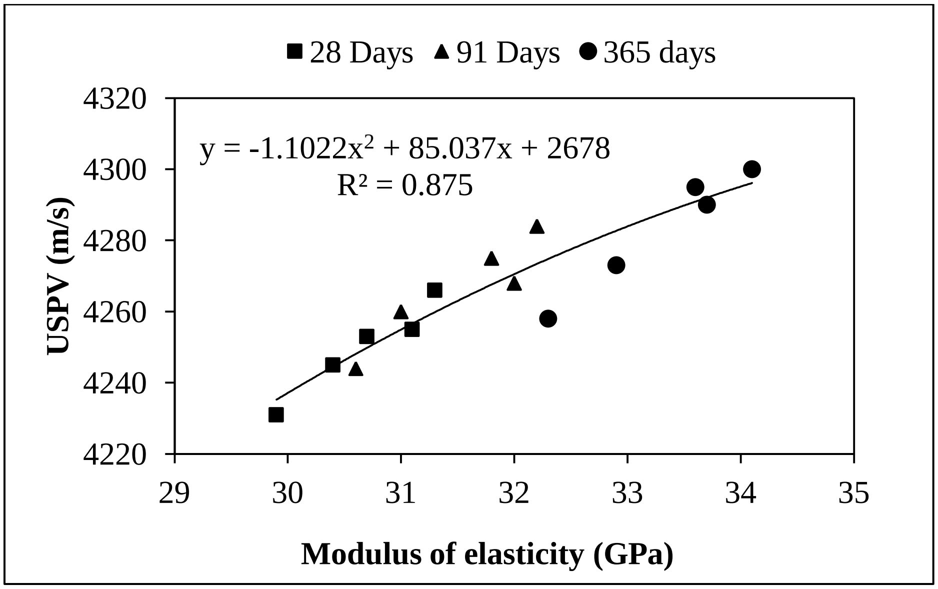


Fig. 4.68: Modulus of Elasticity verses USPV

The regression analysis amongst durability properties (Abrasion resistance, deicing salt scaling resistance and rapid chloride permeability) for all concrete mixes at different ages is shown in Fig. 4.69 to 4.74. Regression equations and correlation coefficient are presented in Table 4.8. A polynomial relationship in the form of $y = ax^2+bx+c$ seems to best fit the data with highest R^2 value (0.9435 to 0.9823) indicating strong correlation. The high values of correlation coefficient indicate that depth of wear has a strong relationship with other durability properties (scaling resistance and rapid chloride penetrability) and USPV.

Table 4.8 Regression Analysis between Durability Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Abrasion Resistance verses RCPT	$y = 170.13x^2 - 223.4x + 654.67$	0.958
Abrasion Resistance verses Scaling Resistance	$y = 0.1795x^2 - 0.1857x + 0.1708$	0.9676
RCPT verses Scaling Resistance	$y = 1E\text{-}08x^2 + 0.0013x - 0.5618$	0.9435
Abrasion Resistance verses USPV	$y = 2.881x^2 - 83.839x + 4444.1$	0.9782
Scaling Resistance verses USPV	$y = 52.927x^2 - 183.73x + 4368.5$	0.9597
RCPT verses USPV	$y = 0.0446x^2 - 388.94x + 847746$	0.9823

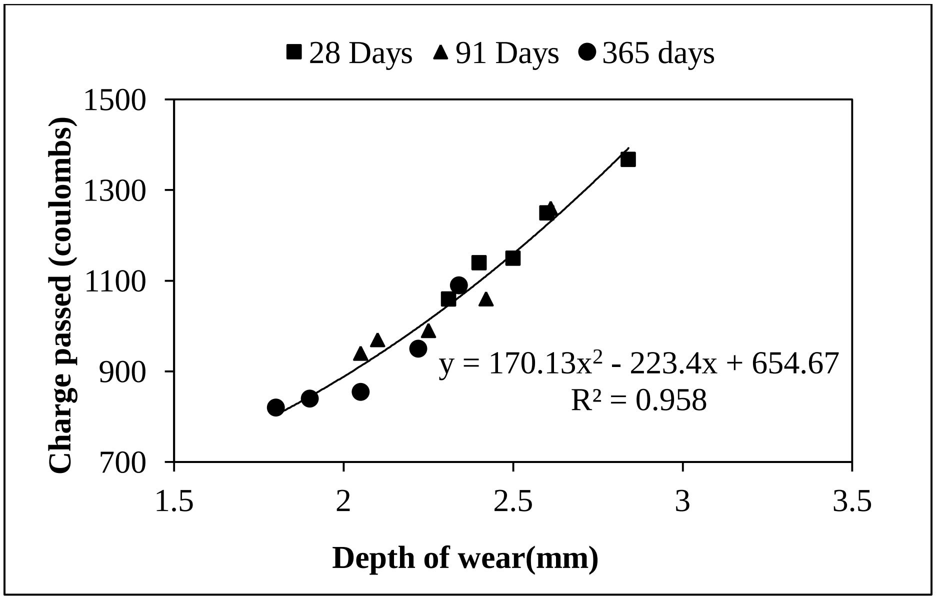


Fig. 4.69: Abrasion Resistance verses RCPT

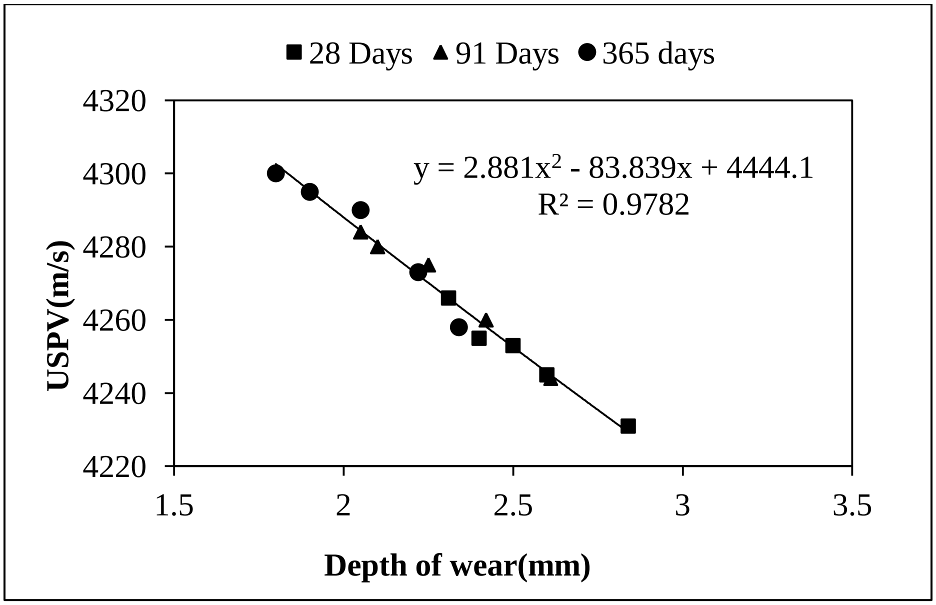


Fig. 4.70: **Abrasion Resistance verses USPV**

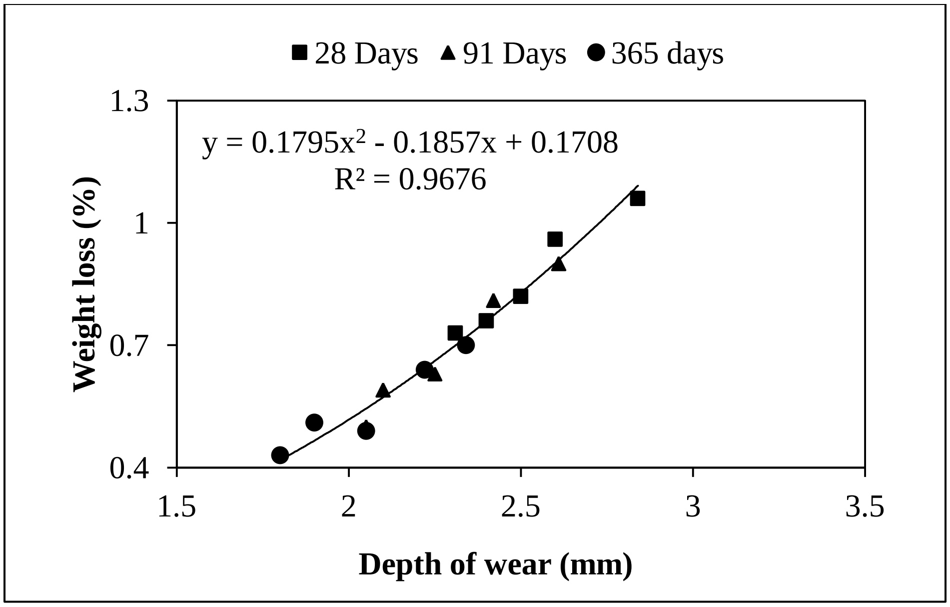


Fig. 4.71: Abrasion Resistance verses Scaling Resistance

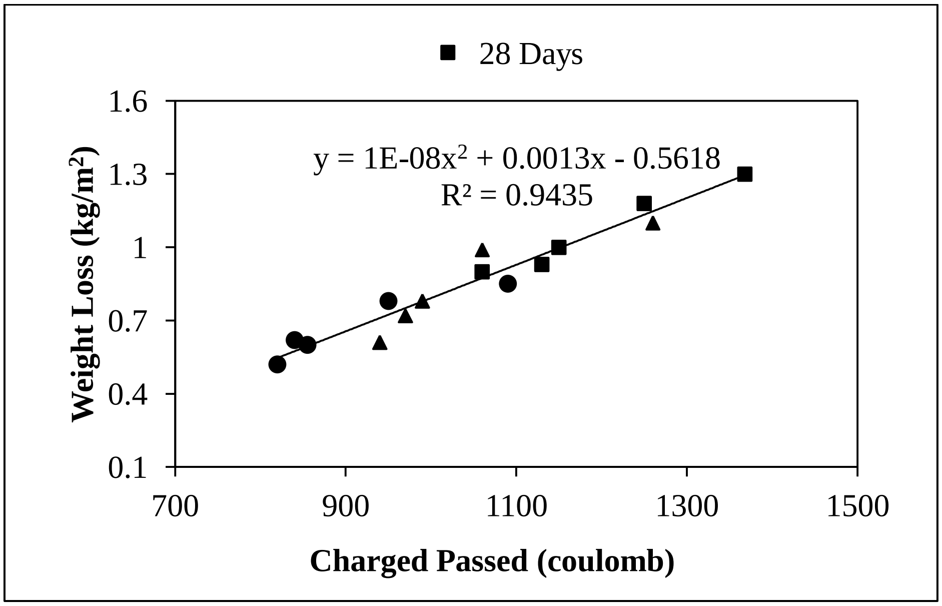


Fig 4.72: RCPT verses Scaling Resistance

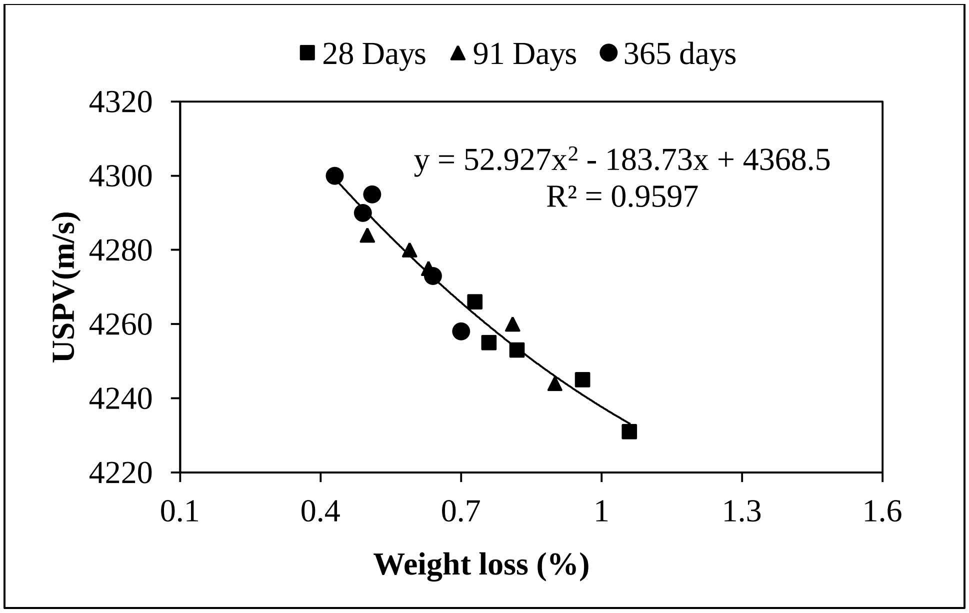


Fig. 4.73: Scaling Resistance verses Ultrasonic Pulse Velocity

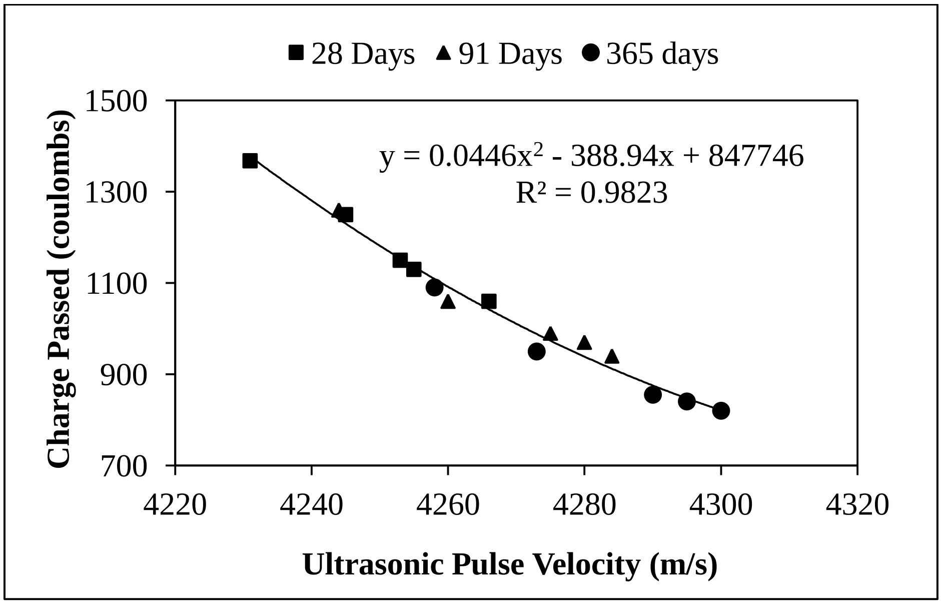


Fig. 4.74: Ultrasonic pulse velocity verses RCPT

Relationship between strength and durability properties is shown in Figs.4.75 to 4.83. A polynomial equation was the best fit with correlation coefficient (R^2) value varied from 0.8453 to 0.9443. Higher value of correlation coefficient indicates a strong relationship between strength and durability properties. The voids between the particles of concrete matrix filled by the fine particles of waste foundry sand, hence concrete matrix become denser which lead to an increase the compressive strength and splitting tensile strength and decreased the rapid chloride permeability of concrete. The high values of correlation coefficient indicates that depth of wear has a strong relationship with strength properties (compressive and splitting tensile) and well as modulus of elasticity.

Table 4.9 Regression Analysis between Strength and Durability Properties

PROPERTIES RELATIONSHIP	EQUATIONS	CORRELATION COEFFICIENT (R^2)
Compressive Strength verses RCPT	$y = 1.8604x^2 - 216.97x + 7109.1$	0.9443
Compressive Strength verses Abrasion Resistance	$y = 0.0024x^2 - 0.2981x + 10.928$	0.8863
Compressive Strength verses Scaling Resistance	$y = 0.0023x^2 - 0.2583x + 7.82$	0.8675
Splitting tensile strength verses RCPT	$y = 328.51x^2 - 3694x + 11075$	0.857
Splitting tensile strength verses Abrasion Resistance	$y = -0.0813x^2 - 0.4426x + 6.0527$	0.8849
Splitting tensile strength verses Scaling Resistance	$y = 0.2526x^2 - 3.0856x + 9.5397$	0.8453
Modulus of elasticity verses RCPT	$y = 21.759x^2 - 1512.1x + 27103$	0.9086
Modulus of elasticity verses Abrasion Resistance	$y = 0.03x^2 - 2.1245x + 39.512$	0.8845
Modulus of elasticity verses Scaling Resistance	$y = 0.0301x^2 - 2.0641x + 35.829$	0.9109

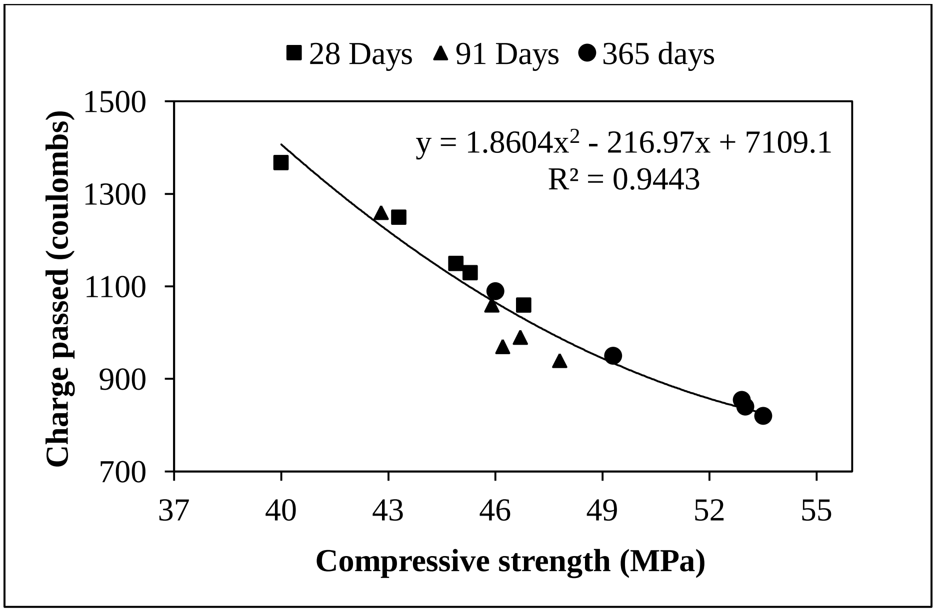


Fig. 4.75: Compressive Strength verses RCPT

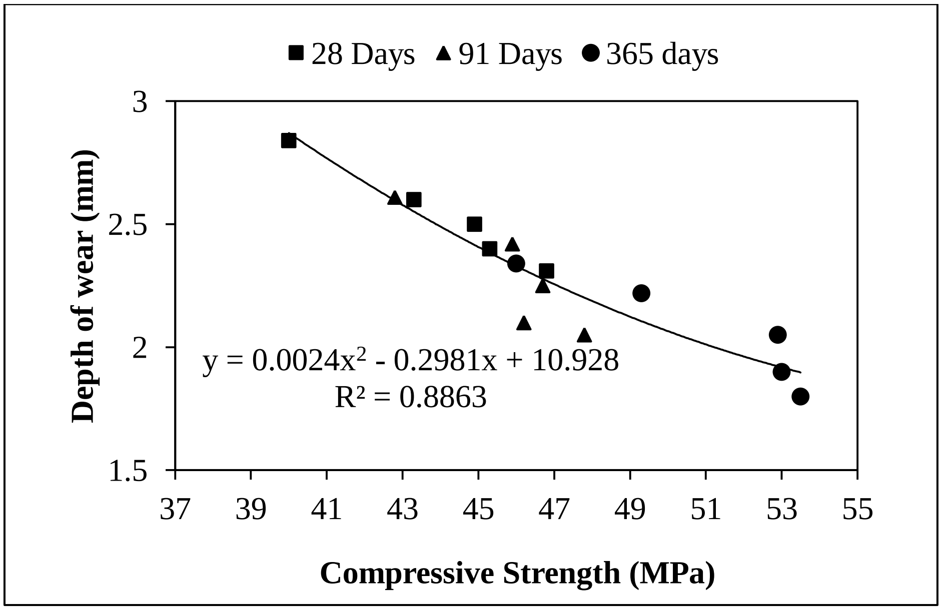


Fig. 4.76: Compressive Strength verses Abrasion Resistance

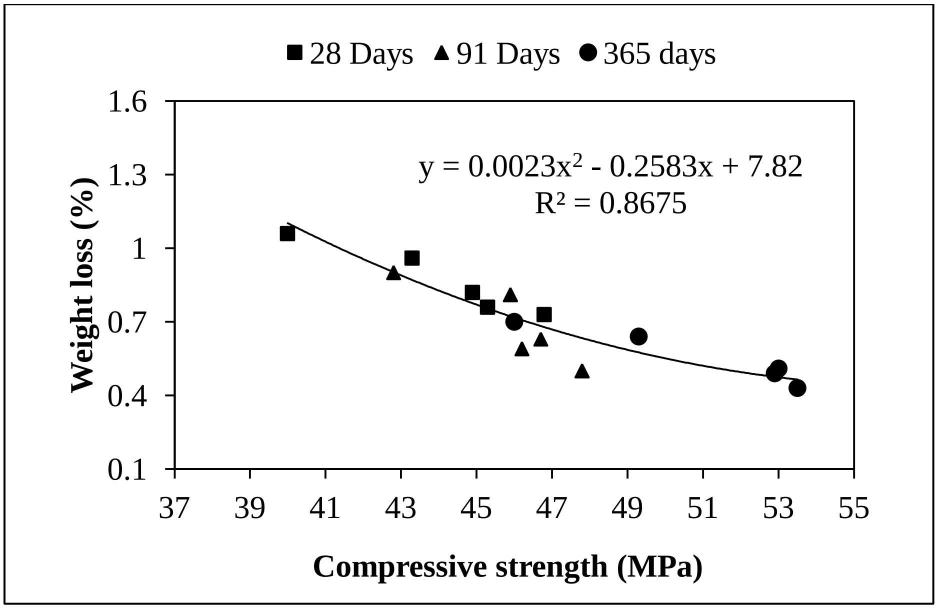


Fig. 4.77: Compressive Strength verses Scaling Resistance

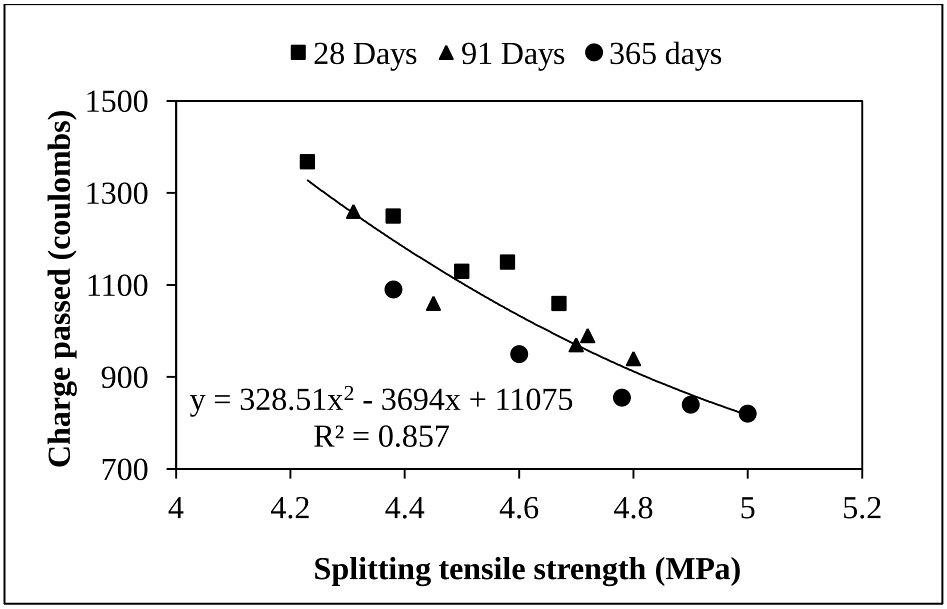


Fig. 4.78: Splitting Tensile Strength verses RCPT

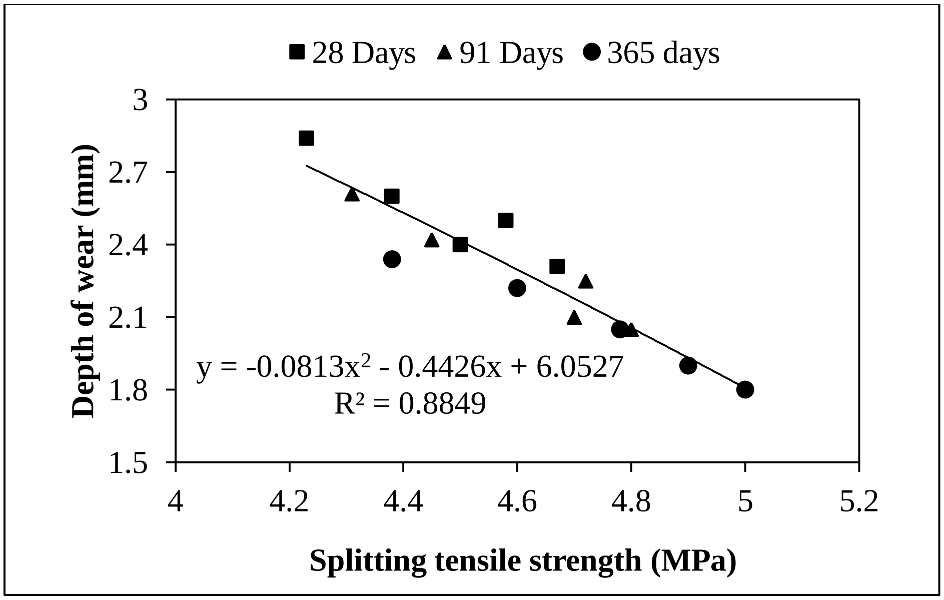


Fig. 4.79: Splitting Tensile Strength verses Abrasion Resistance

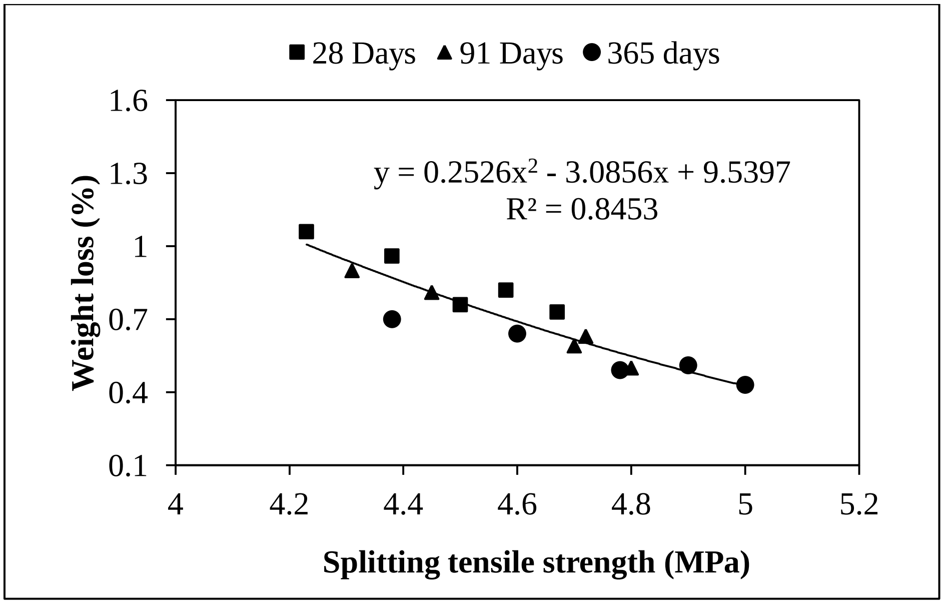


Fig. 4.80: Splitting Tensile Strength verses Scaling Resistance

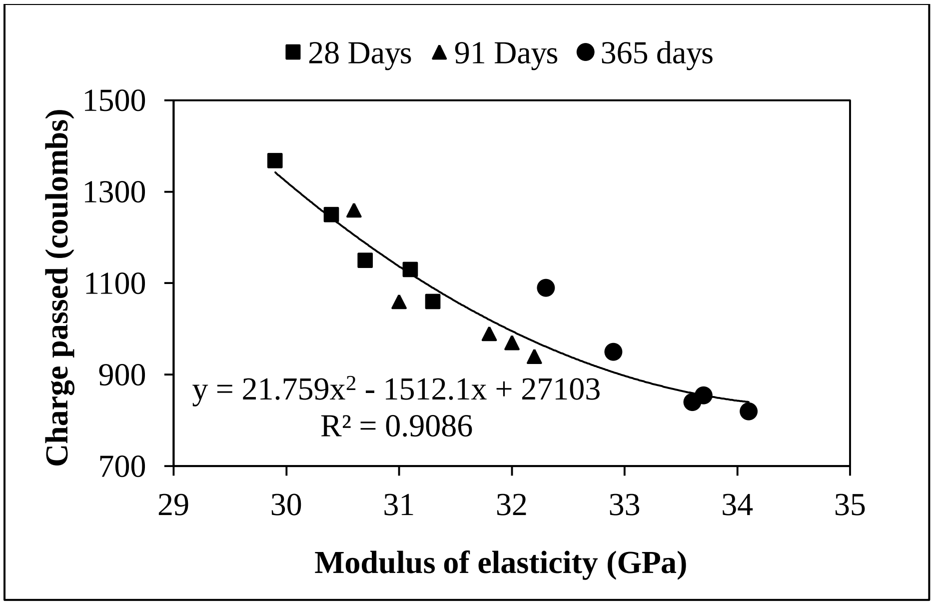


Fig. 4.81: Modulus of Elasticity verses RCPT

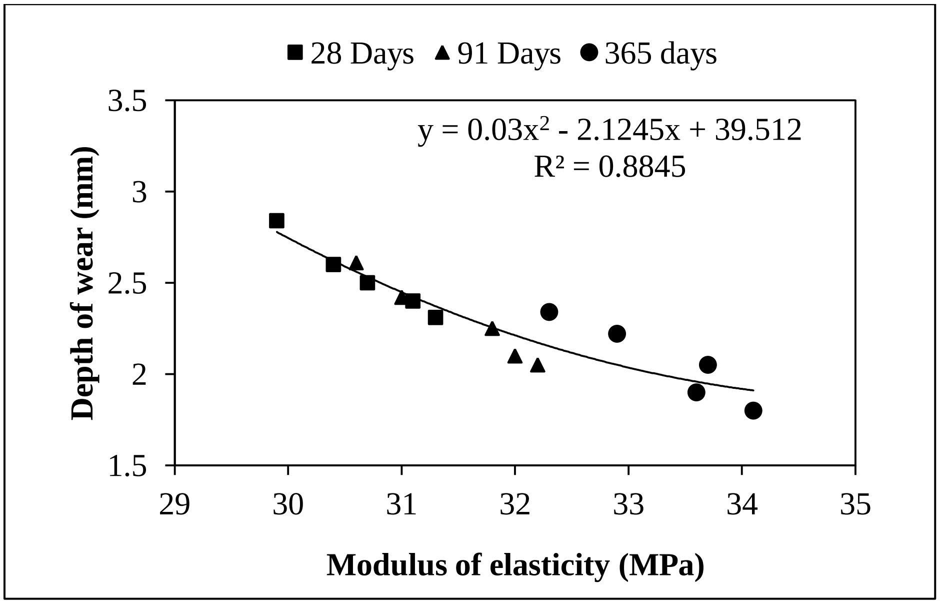


Fig. 4.82: Modulus of Elasticity verses Abrasion Resistance

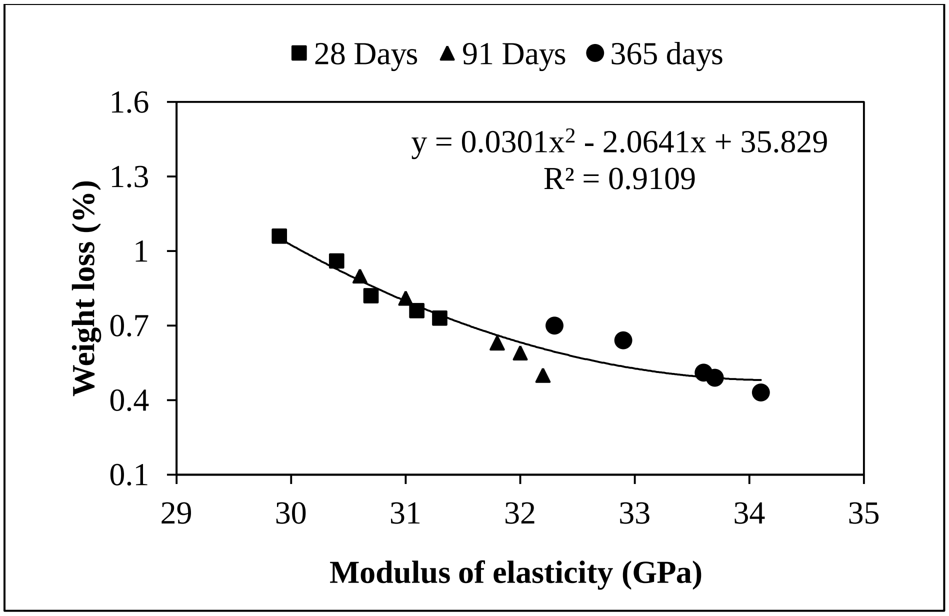


Fig. 4.83: Modulus of Elasticity verses Scaling Resistance

4.11 X- RAY DIFFRACTION (XRD) STUDIES

In present investigation, XRD analysis was carried out only for M20 Grade concretes mixes. It was done with the view that in M20 Grade of concrete mixes, influence of WFS was more pronounced in comparison with M30 Grades of concrete mixes.

The X-ray diffraction pattern and analysis of concrete mixes of M20 Grade of concrete at the age of 28 day are shown in Fig 4.84 to 4.88. it can be seen from these figures that in all concrete mixes, peak of the dicalcium silicate (C_2S), tricalcium silicate (C_3S) and tetracalcium alumino ferrite (C_4AF) are not visible indicating that they are totally consumed. Silica oxide (SiO_2) peak indicated free silica present in concrete mixes. At 0% WFS, replacement peak observed was 3500. Same peak intensity was observed at 5% replacement (M-2). For mix M-3 (10%WFS) peak was near to 2500. It was observed that for mix M-4(15%WFS) peak intensity was minimum 2000 and at 20% WFS replacement, it goes to increase by more than 2500. Similar types of results are reported by Basar et al. (2012).

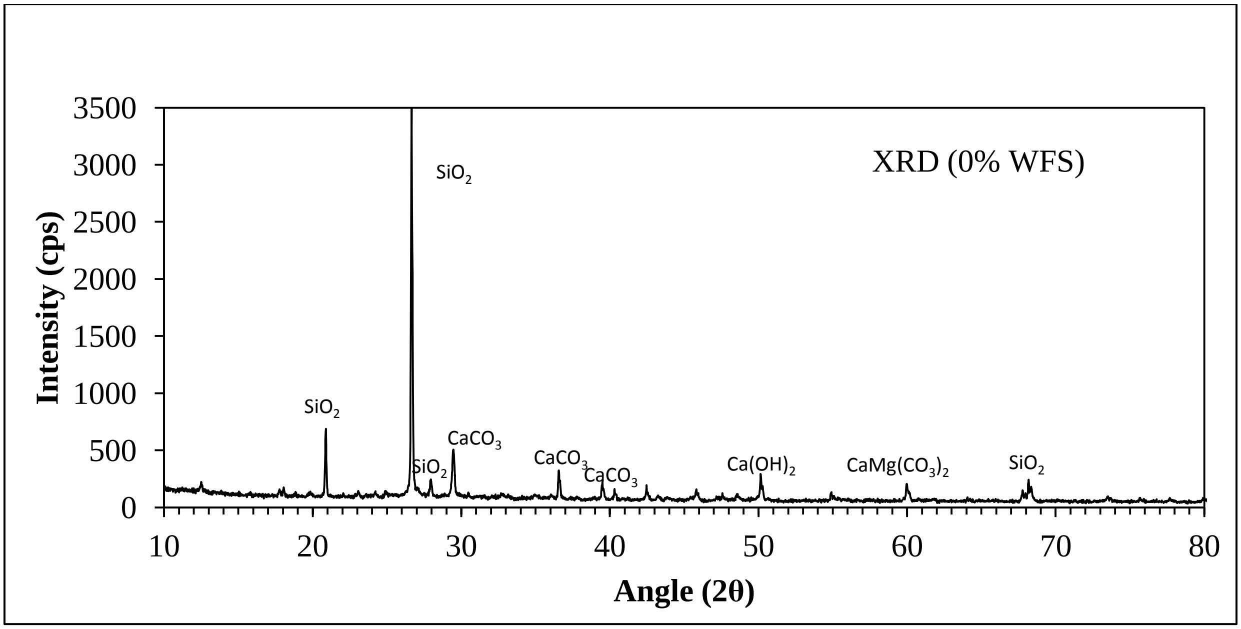


Fig. 4.84: X-Ray Diffraction Pattern of Mix M-1(0%WFS)

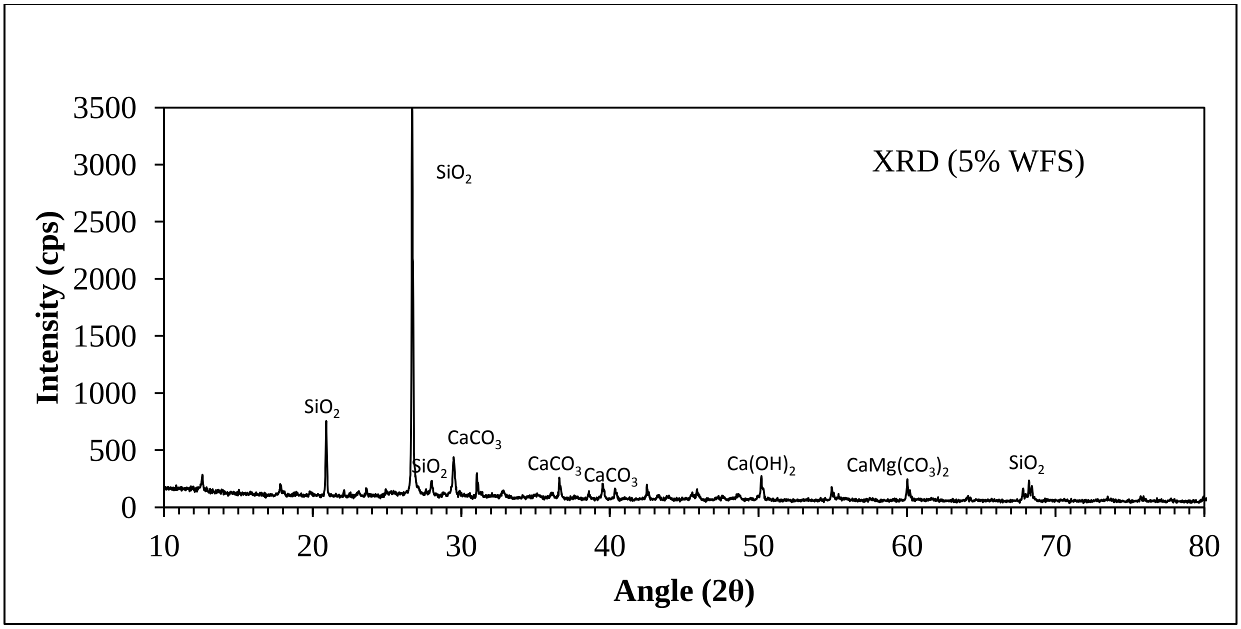


Fig. 4.85: X-Ray Diffraction Pattern of Mix M-2(5%WFS)

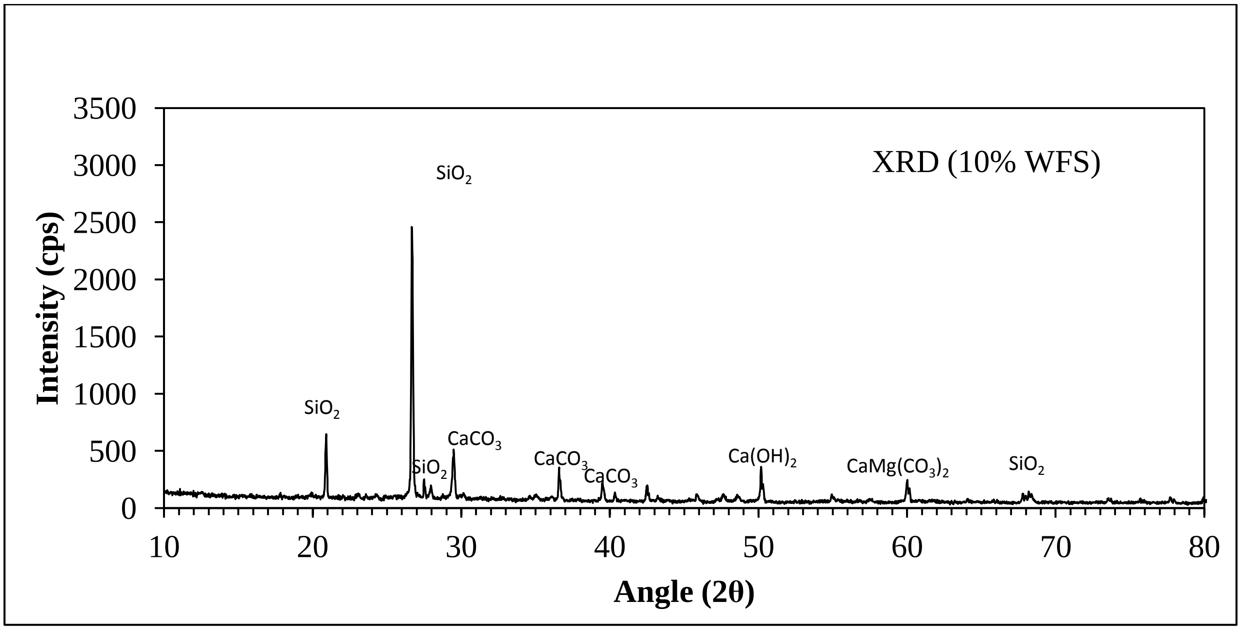


Fig. 4.86: X-Ray Diffraction Pattern of Mix M-3(10%WFS)

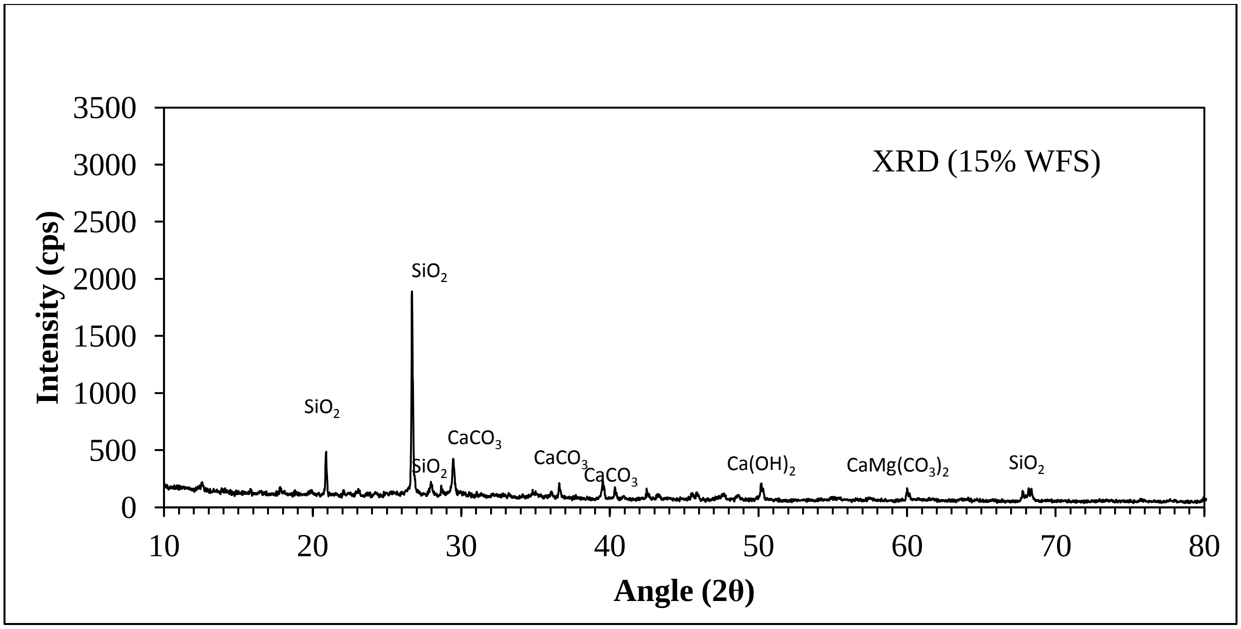


Fig. 4.87: X-Ray Diffraction Pattern of Mix M-4(15%WFS)

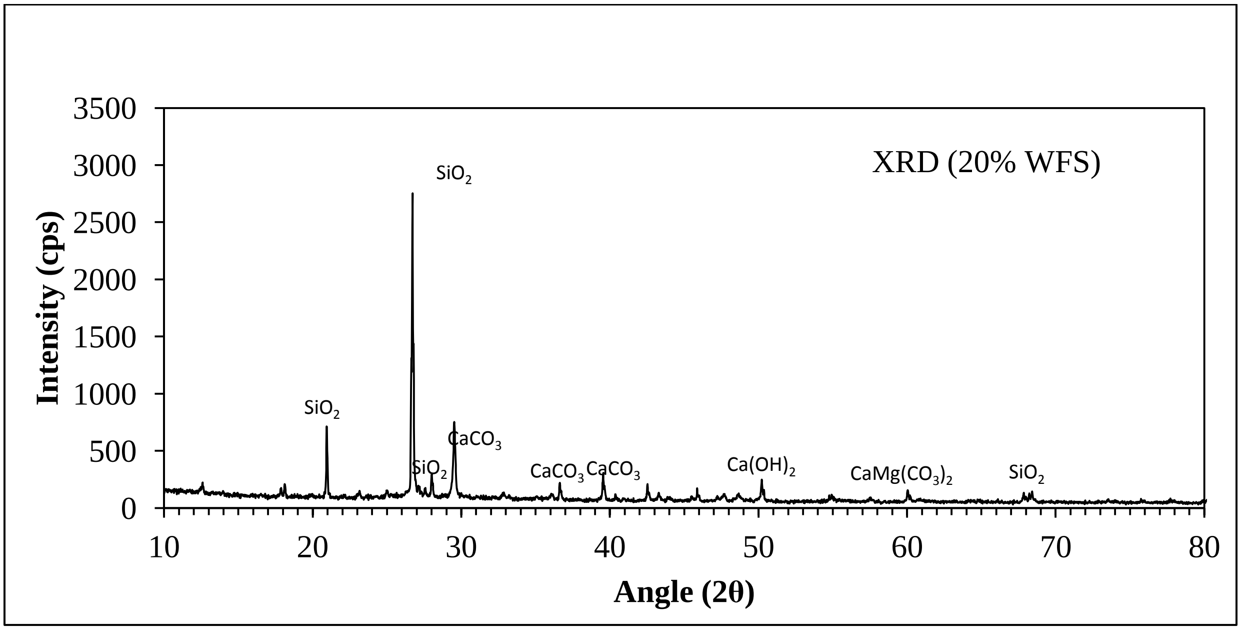


Fig. 4.88: X-Ray Diffraction Pattern of Mix M-5(20%WFS)

It was found that with the increase in waste foundry sand percentages in concrete mixes, utilization of silica in C-S-H gel increased. This trend was observed up to 15% replacement of fine aggregate with WFS in concrete. The presence of calcium hydroxide ($Ca(OH)_2$) is very less in all concrete mix which confirms the maximum consumption in the hydration reaction. This help to make dense microstructure and additional development of C-S-H gel, leading to the improvement of microstructure of the concrete, which has resulted in the improvement of the strength and durability properties.

4.12 SUMMARY

In this chapter, the findings of experimental investigations were discussed. Various tests were conducted to determine the effect of waste foundry sand on strength and durability properties of both grades of concrete (M20 and M30). In non destructive testing, rebound hammer and ultrasonic pulse velocity test was performed. Natural sand was replaced with waste foundry sand by 0 to 20% at an interval of 5%. In this investigation it was found that at 15% replacement, WFS showed considerable improvement on strength properties (compressive strength, splitting tensile strength and modulus of elasticity) and durability properties (abrasion resistance, rapid chloride penetration resistance and deicing salt surface scaling resistance) of both grades of concrete

CHAPTER – 5

CONCLUSIONS

5.1 GENERAL

The present work investigated the influence of waste foundry sand as partial replacement of fine aggregate (sand) on the properties of two grades (M20 & M30) of concrete. On the basis of the results from the present study, following conclusions are drawn.

5.2 STRENGTH PROPERTIES

5.2.1 Compressive Strength

i. Compressive strength of both grades of concrete mixes (M20 and M30) increased due to replacement of fine aggregate with waste foundry sand. However, compressive strength observed for both grades of concrete mixes were appropriate for structural uses.

ii. M20 (30 MPa) grade concrete mix obtained increase in 28-day compressive strength from 30MPa to 37.8MPa on 15% replacement of fine aggregate with WFS, whereas it increase was from 40MPa to 46.8MPa for M30 grade of concrete mix. Maximum strength was achieved with 15% replacement of fine aggregate with WFS. Beyond 15% replacement it goes to decrease for both grades of concrete, but was still higher than control concretes

iii. Effect of inclusion of WFS was better effect on M20 grade of concrete mixes rather than M30 grade of concrete mixes. The rate of gain of strength for M20 grade of concrete mixes observed to be more than M30 grade of concrete mixes at all percentage replacement.

iv. Compressive strength also increased with increase in age for both grades of concrete. The rate of compressive development of waste foundry sand concrete mixes were higher compared to no waste foundry sand concrete mixes.

5.2.2 Splitting Tensile Strength

i. Concrete mixes obtained linear increase in 28-day splitting tensile strength from 3.42MPa to 3.86MPa for M20 grade of concrete mix (M-1) and 4.23MPa to 4.67MPa for M30 grade of concrete mix (M-6) on replacement of fine aggregate with waste foundry sand at various percentages of 5% to 20%.

ii. Splitting tensile strength of all concrete mixes for both grades of concrete (M20 and M30) was found to increase with increase in with varying percentage of waste foundry sand.

iii. At the age of 28 days, splitting tensile strength of M20 grade of concrete mix (M-1) increased by 12.8% whereas increase was 10.4% for M30 grade of concrete mix (M-6) at same age. Development of splitting tensile strength was more in M20 grade mixes than M30 grade mixes.

iv. Maximum increase in splitting tensile strength was observed at 15% replacement of fine aggregate with waste foundry sand at all age for both grades of concrete mixes (M20 and M30).

5.2.3 Modulus of Elasticity

i. At 28 days, modulus of elasticity increased from 23.8GPa to 25.2GPa for M20 grade of concrete mix(M-1) and 29GPa to 31.3GPa for M30 grade of concrete mix (M-6) on replacement of fine aggregate with waste foundry sand with various percentage from 0% to 20%

ii. Modulus of elasticity for M20 and M30 grades of concrete mixes was observed to increase with increase in age. Mix M-4 (15%WFS) exhibited better modulus of elasticity compared to control mix M-1 (0%WFS) for M20 grade concrete. Similarly, mix M-9(15%WFS) showed higher modulus of elasticity than control mix M-6(0%WFS) for M30 grade of concrete. Beyond 15% replacement, with 20% WFS, modulus of elasticity goes to decrease for both grades of concrete but it was more than control one.

iii. With inclusion of waste foundry sand, improvement in the modulus of elasticity of M20 grade concrete mixes was better than M30 grade concrete mixes.

In above conclusions, it was found that inclusion of waste foundry sand as a partial replacement of fine aggregate in concrete mixes gives better effect on strength properties of concrete. Enhancement in strength properties was observed due to addition of waste foundry sand. Strength properties results indicate that waste foundry sand could be very conveniently used in making good quality concrete and construction materials.

5.3 DURABILITY PROPERTIES

5.3.1 Abrasion Resistance

i. Waste foundry sand concrete mixes showed higher abrasion resistance (less depth of wear) than that of concrete mixes which contain no waste foundry sand. Abrasion loss of waste foundry sand concrete mixes decreased as the replacement of waste foundry sand increased.

ii. Maximum abrasion resistance was observed at 15% replacement of fine aggregate with waste foundry sand for both grades of concrete (M20 and M30). For example, at the age of 28 day, concrete mix M-4(15%WFS) showed 19.25% more abrasion resistance than control mix M-1(0%WFS) for M20 grade concrete whereas increase in abrasion resistance was 18.6% for mix M-9(15% WFS) than control mix M-6(0%WFS) for m30 grade of concrete.

iii. Improvement in abrasion resistance was approximately same for both grades of concrete mixes. Very marginal increase was found in M20 grade of concrete mixes than M30 grades of concrete mixes.

iv. Results have indicated that concrete made with (up to 15%) WFS could suitable be used for making structural concretes, as well as for applications where abrasion is also important parameter.

5.3.2 Rapid Chloride Permeability Resistance

i. Chloride permeability resistance of concrete mixes increased with the increase in waste foundry sand content for both grades of concrete (M20 and M30).

ii. RCPT value (Coulombs) decreased with the increase in WFS content up to 15% WFS, which indicate that concrete has become denser. This aspect has also been reflected by the compressive strength result up to 15% WFS. However, at 20% WFS, there is slight increase in coulomb value with references to 15% WFS but it more than control one. At the age of 28 days, all concrete mixes for both grade of concrete (M20 and M30) show Low Permeability against chloride.

iii. All concrete mixes (with and without waste foundry sand) for M20 grade of concrete come under "low" permeability against chloride at all age as per ASTM standards. Only concrete mix M-4(15% WFS) comes under very low permeability at 365 days of curing. Whereas concrete mix M-7, M-8, M-9 and M10 for M30 grade of concrete come under very low permeability at the age of 365 days.

5.3.3 Deicing Salt Surface Scaling Resistance

i. Waste foundry sand gave better effect on resistance of concrete mixes against deicing salt surface scaling for M20 and M30 grades of concrete. Resistance increased with the increase in waste foundry content in concrete mixes. Deicing salt scaling resistance also increased with increase in age of curing.

ii. Scaling resistance was affected by the poor voids system in concrete matrix. Fine particles of waste foundry sand filled the voids between the particles of concrete matrix and increased its surface hardness. The hardness increases the resistance against deicing salt scaling.

iii. The scaling resistance of concrete mixes for both grades of concrete (M20 and M30) was significantly influenced by the waste foundry sand. Maximum resistance was observed at 15% replacement of fine aggregate with WFS. All concrete mixes for M20 and M30 grades of concrete showed weight loss lower than control mix (M-1 & M-6). At 28 days, weight loss was reduced by 1.06% to o.78% for M20 grade of concrete mixes and it was reduced by 1.06% to 0.73% for M30 grade of concrete mixes.

The test data for all the concrete mixes with and without waste foundry sand for M20 and M30 grades of concrete show excellent results with respect to abrasion resistance, rapid chloride ion permeability and deicing salt scaling resistance. Results have indicated that concrete made with (up to 15%) WFS could suitable be used for making structural concretes.

5.4 ULTRASONIC PULSE VELOCITY

In this investigation, ultrasonic pulse velocity method was used to predict the quality of concrete and to know the effect of waste foundry sand on quality of concrete in term of homogeneity and uniformity of concrete.

Result showed that ultrasonic pulse velocity increased with the inclusion of waste foundry sand in both grades of concrete (M20 and M30). All concrete mixes of both grades of concrete satisfied the criteria of BIS 13311 (part-1) 1992 Ultrasonic pulse velocity of all concrete mixes lies between 3500m/s to 4500m/s. it means that with addition of WFS in concrete, quality of concrete mixes improved. Maximum velocity was observed at 15% replacement of fine aggregate with WFS for both grades of concrete. It also increased with age.

5.5 REBOUND HAMMER

Rebound hammer is used to predict the compressive strength of the concrete. It is not an accurate method. According to BIS: 13311 (part 2)-1992, accuracy of prediction of concrete strength in structure is ± 25 percent. Due to inclusion of waste foundry sand content in concrete, the compressive strength was observed higher than that of control one. It was also found that compressive strength was increased with age (91days and 365 days) in both grades of concrete.

5.6 STATISTICAL ANALYSIS

In this analysis, correlation between the strength and durability properties was investigated. It was observed that there is a good correlation between strength and durability properties for both grades of concrete. A polynomial relationship in the form of $y = ax^2+bx+c$ seems to best fit the data with R^2 values.

i. Coefficient of correlation amongst strength properties (compressive strength, splitting tensile strength and modulus of elasticity) is very high (from 0.9584 to 0.9775). These strength properties also have a very strong relation with ultrasonic pulse velocity (USPV).

ii. Very strong relationship was observed between the abrasion resistance, salt scaling resistance and rapid chloride permeability resistance. Value of correlation coefficient varied from 0.9274 to 0.9693. It means that inclusion of waste foundry sand in concrete led to decrease the wear depth and increase the scaling resistance and chloride permeability resistance.

iii. The high values of correlation coefficient indicates that depth of wear has a strong relationship with strength properties (compressive and splitting tensile) and well as modulus of elasticity. Generally, an increase in strength and modulus of elasticity lead to an increase in abrasion resistance of concrete.

5.7 X- RAY DIFFRACTION STUDIES

i. In all concrete mixes for M20 grade of concrete, C_2S, C_3S and C_4AF are totally consumed

ii. Up to 15% replacement of fine aggregate with WFS, utilization of silica in C-S-H gel increased.

iii. The presence of calcium hydroxide ($Ca(OH)_2$)is very less in all concrete mix which confirm the maximum consumption in the hydration reaction and additional development of C-S-H gel led to improve the strength and durability properties of both grade of concrete.

5.8 SUMMARY

This chapter deals with the conclusions based of the findings of strength and durability properties of both grades of concretes. Inclusion of waste foundry sand as a partial replacement of fine aggregate in concrete improved the strength and durability properties of both the grades of concrete. Further, concrete made with 15% replacement of natural sand with WFS could suitable be used for making structural concretes.

LIST OF PUBLICATIONS FROM PRESENT WORK

i. "Effect of waste foundry sand (WFS) as partial replacement of sand on strength, ultrasonic pulse velocity and permeability of concrete". Construction and Building Materials, Volume 26, Issue 1, January 2012, Pages 416-422

ii. "Abrasion Resistance and Strength Properties of Concrete Containing Waste Foundry Sand". Construction and Building Material, Volume 28, Issue 1, March 2012, Pages 421-426.

iii. "Utilization of waste foundry sand (WFS) in concrete manufacturing". Resources, Conservation and Recycling, Volume 55, Issue 11, September 2011, Pages 885-892.

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