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Technical Note

EFFECT OF SIZE AND TYPE OF FINE AGGREGATE ON MECHANICAL AND SORPTIVITY CHARACTERISTICS OF CONCRETE

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ABSTRACT

The present study investigated the effect of fine aggregate characteristics namely individual size, grade and type on the Compressive, split tensile and flexure strengths of concrete mixes. Two types, river sand/ Natural sand and Foundry sand four single sizes namely 4.75mm, 2.36mm, 1.18 mm, 0.600 mm, were considered to prepare M20 and M40 concretes in the present research work. The suitability of Foundry sand (FS) to replace river sand in concrete production was addressed in this study. Slump test was performed on fresh concrete to evaluate workability while compressive, indirect tensile strength, flexure strength and Sorptivity tests were performed on hardened concrete. Strength and sorptivity characteristics measured optimal Values with mixes prepared using 0.6mm fine aggregate and concrete with foundry sand exhibited superior performance. Ultrasonic Pulse velocity (UPV) test was also conducted to assess the quality of concrete. The overall test results revealed that foundry sand can be utilized in concrete mixtures as a good substitute of natural sand. In addition to conservation of river sand, a better and meritorious way of disposing wastes is using Foundry sand in concrete production to our advantage.

Keywords: Foundry sand; natural sand; sorptivity; ultrasonic pulse velocity (UPV); compressive strength; split tensile strength.

1. INTRODUCTION

The world wide consumption of sand as fine aggregate in concrete production is very high, and several developing countries have encountered some strain in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years. A situation

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that is responsible for this scenario can be attributed to increase in the price of sand, and scarcity of river sand which is one of the constituent material used in the production of conventional concrete [1]. To overcome the stress and demand for river sand, researchers and practitioners in the construction industries have identified some alternative namely fly ash, slag, limestone powder and siliceous stone powder [2, 3]. Construction industry also conducted research on the utilization of waste products in concrete. Some of waste products are fly ash, rice husk, saw dust, and discarded tires, plastic, glass rock, steel slugs, stone dust and ceramic. Each waste product has its specific effect on properties of fresh and hard concrete. The use of waste products in concrete not only makes it economical but also solves some of the disposal problems [4]. Characteristics of aggregate such as shape, size and surface textures play a predominant role in achieving desired properties of fresh concrete such as workability, flowability, mobility, dimensional stability, compactibility and resistance to segregation. It is proved that, compaction or packing effort will be governed by whether aggregates used are continuous graded (well graded) or uniformly graded (poorly graded). It governs the volume of voids in the concrete, in turn deciding the volume of cement to be consumed per unit quantity. In the case of well graded aggregates usage, particles are packed pucca, the cement requirement becomes less towards filling voids and additional quantity can be utilized for surface coating of aggregate [5]. Some alternative materials have already been used as a part of natural sand for obvious advantages. Safiuddin et. al [6] studied the effects of quarry waste fine aggregate, as a partial replacement of natural sand, on fresh and hardened properties of four different types of concrete mixtures prepared. It was found that quarry waste fine aggregate enhanced the slump, unaffected the unit weight, air content & ultrasonic pulse velocity of the concretes, decreased the compressive strength while marginally increasing the dynamic modulus of elasticity and initial surface absorption. Baâli et. al.[7] analyzed the physical and chemical properties of dune sand and calcined clay sand, as well as the characteristics of the mortar made with mixed sand such as, the workability, the density and the mechanical responses namely compressive and flexural strengths. Joel [8] investigated the suitability of Crushed granite fine (CGF) to replace river sand in concrete production for use in rigid pavement. Slump, compressive and indirect tensile strength tests were performed on fresh and hardened concrete. Based on economic analysis and results of tests, river sand replaced with 20% CGF is recommended for use in the production of concrete for use in rigid pavement.

Research Significance

Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed “foundry sand.” Foundry sand is basically fine aggregate. The use of industrial by-products in concrete not only helps to reduce the greenhouse gas emissions but results in environmentally friendly concrete, and is often more economical than normal portland-cement concrete. In India, nearly 4700 foundry industries are present and they generate about 50 lakh tones of waste sand every year which causes land, air and ground water pollution. In this study, an attempt is made to utilize the foundry waste sand in concrete making and check the suitability of the same as fine aggregate in concrete, if not disposed properly [9]. The successful utilization of FS as fine aggregate would turn this waste material that causes an environmental load due to disposal problem into valuable resources, reduction in the strain on the supply of natural sand, and economy in concrete production. This work is aimed at determining the suitability of FS to replace river sand in the production of concrete. In the present research work, the effect of individual particle size and type of fine aggregate on mechanical properties viz., Compressive strength, Split tensile strength and flexural strength and sorptivity of concrete was studied.

2. EXPERIMENTAL WORK

2.1 Materials

Ordinary Portland cement of 53-grade with sp. Gravity, std. consistency, IST & FST and fineness values as 3.15, 34%, 45 & 175 min and 6% was used for all the concrete samples. River sand and Foundry sand were used as fine aggregates. The specific gravity was 2.76 for river sand and 2.85 for Foundry sand. Similarly fineness modulus of river sand and Foundry sand were 1.93 and 2.43 respectively. Four single-sized aggregates (1.18 mm, 0.600 mm, 0.300 mm and 0.150 mm) and two types of aggregates (river sand and Foundry sand), were employed and compared with graded aggregate of respective type. The specific gravity and fineness modulus of coarse aggregate (crushed stone) used were 2.69 and 6.85 respectively. Potable water was used for mixing and curing.

2.2 Mixture Proportions

M20 and M40 grades of concretes were designed according to IS: 10262-1982 [10] and the materials were respectively batched in proportions of 1: 1.872: 3.095 / 0.55 and 1: 1.342: 2.532 / 0.40. Eight concrete mixes, 4 each for M20 and M40, with varying types of aggregate (Natural Sand and foundry sand) and Maximum size of aggregate (4.75 mm, 2.36mm, 1.18 mm and 0.60 mm) were considered for the study.

Table 1: Quantities of ingredients of Concrete

Concrete Mix	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Lit)
M20	358.18	670.40	1108.48	195.03
M40	450.00	604.00	1139.40	178.00

2.3 Test Programme and Testing Methods

The test programme consisted of casting 336 specimen including 288 cubes of 150 mm size and 48 prisms of 100x100x500 mm size to evaluate compressive strength, split tensile strength, modulus of rupture and sorptivity in the present work.

2. 3. 1 Fresh state Property-Workability

Slump test was employed to evaluate the workability of concrete [11]. The results are shown in Table -2.

2. 3.2 Hardened state Properties

Compressive Strength Test: This test was performed on 150mm cubes according to IS: 516-1959 [12] on a digital CTM of 3000 KN capacity.

Split Tensile Strength Test: This test was performed according to IS: 5816-1999 [13]. The indirect tensile strength was determined by splitting cube (150mm) samples in a digital CTM of 3000 KN capacity.

Table 2: Variation of Slump with Size of Fine Aggregate

Concrete Mix	MSA (mm)	Slump (mm) of Mix with		Concrete Mix	MSA (mm)	Slump (mm) of Mix with	
		Natural Sand	Foundry Sand			Natural Sand	Foundry Sand
M20	4.75	115	113	M40	4.75	90	88
	2.362	111	107		2.362	87	85
	1.18	108	102		1.18	83	82
	0.60	103	98		0.60	81	79

Flexural Strength Test: In order to determine the flexure strength of concretes with Natural sand (NS) and Foundry sand (FS), standard prisms of 100x100x500 mm size were tested to failure under static two point loading, on 100.0 tons capacity Universal Testing Machine, in accordance with IS: 516-1959 [12].

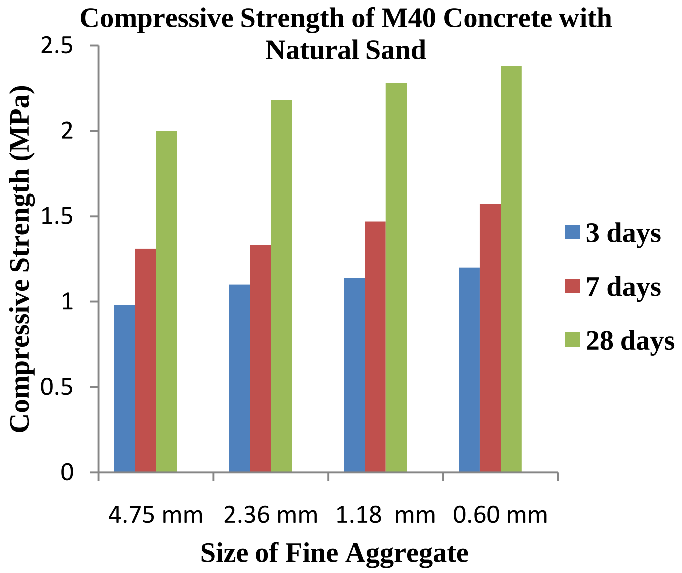
Sorptivity Test: The durability of concrete largely depends on the ease with which fluids enter and move through the matrix. Sorptivity characterizes the material's ability to absorb and transmit water through it by capillary suction. A more important factor related to durability incase of above ground structures is Sorptivity. It is determined using test cubes of 150 mm size as per the outlined procedure for sorptivity test [14], after 28 days of conventional wet curing. The sorptivity can be determined by the measurement of capillary rise absorption rate on reasonably homogeneous materials. Water was used as the test fluid. The sample was rested on nuts to allow free access of water to the inflow surface. The water level was kept not more than 5 mm or so above the base of the specimen. The quantity of absorbed fluid in a time period of 30 minutes was measured by weighing the specimen. Surface water on the specimen was wiped off with a damped tissue. Sorptivity value is calculated using the formula:

$s = \frac{I}{t^{\frac{1}{2}}}$; Where s is sorptivity in $\frac{mm}{\sqrt{min}}$; t is the elapsed time in min; and $I = \frac{\Delta W}{Ad}$; ΔW = increase in weight (gms); A = surface area of specimen through which water penetrates mm^2; and d = the density of water (gm/mm^3). Water sorptivity of various concrete mixes was determined after 3, 7 and 28 days of curing.

Non-destructive Testing: Ultrasonic Pulse velocity (UPV) test was conducted on M20 and M40 concrete cubes of 150 mm size, prepared with NS and FS of different particle sizes, after 3, 7 and 28 days of curing as per IS: 13311-1992 (Part-1) [15] to assess the quality of concrete.

3. RESULTS AND ANALYSIS

Workability: Table. 2 presents the results of slump test conducted on various mixes to assess the workability of concrete. Workability of concrete assessed through slump test measured decreasing slumps with reducing size of fine aggregate, irrespective of the type of fine aggregate, in M20 and M40 grade concretes studied. But, workability is found to be better in mixes containing natural sand.



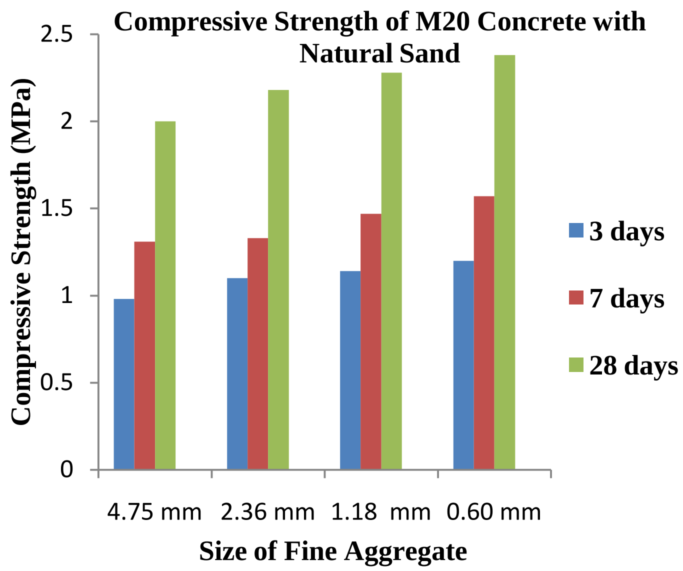


Figure 1. Variation of Compressive Strength with size of Fine aggregate (NS)

Compressive Strength: Fig. 1 depict the variation of compressive strength, of M20 and M40 concretes containing natural sand (NS) as fine aggregate, with maximum size of aggregate (MSA) while Fig. 2 show the same for concrete with foundry sand (FS) as aggregate. The 3, 7 and 28 days compressive strength of M20 and M40 concrete mixes are found to increase with decreasing size of fine aggregate. Optimum strength was obtained in mixes of 0.6mm MSA in all the mixes considered, irrespective of the type of fine aggregate. As size of aggregate decreased from 4.75mm to 0.60mm, 28-day compressive strength of M20 and M40 concretes respectively increased from 27.71 - 28.51 MPa (2.89%) & 48.6 – 49.89 MPa (2.65%) with NS and from 29.71 – 31.29 MPa (5.32%) & 51.24 – 52.48 MPa (2.42%) with FS. As it could be seen, 28-day optimal compressive strengths are higher in mixes made of foundry sand than those of natural sand by 9.75% and 5.19% in M20 and M40 grades respectively. This could be attributed to the fact that finer size particle contribute to denser packing and result in more durable and less water absorbing concrete. It can be observed that strengths are higher in mixes prepared with foundry sand than those of natural sand.

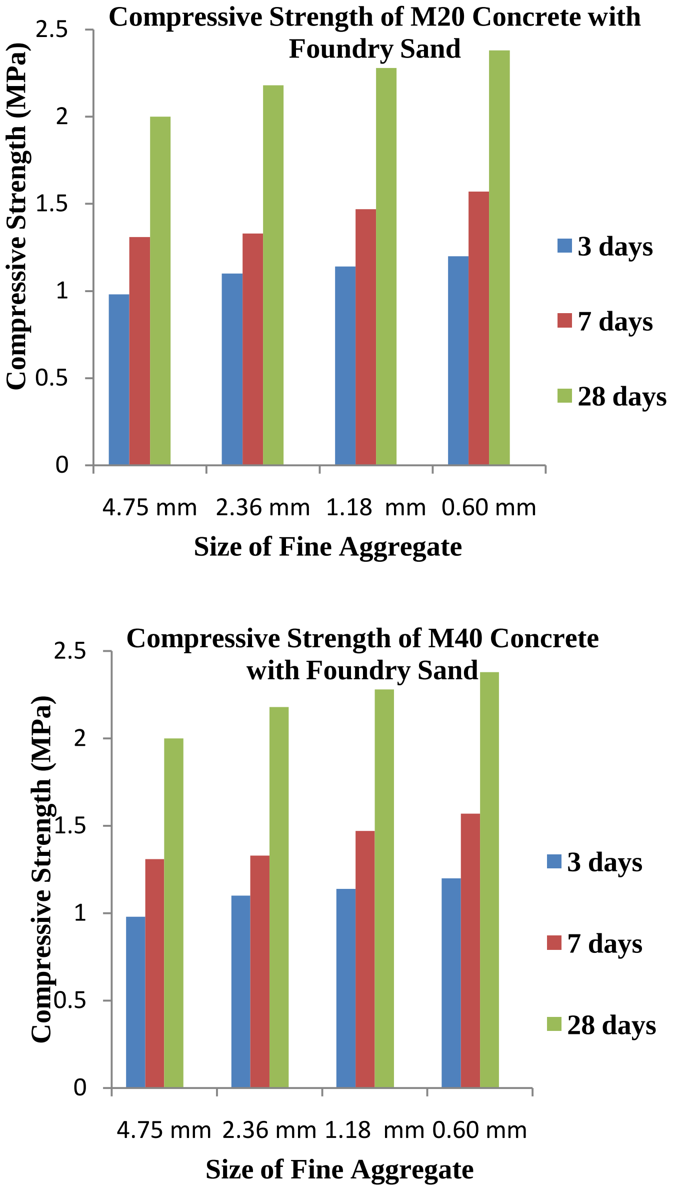


Figure 2. Variation of Compressive Strength with size of Fine aggregate (FS)

Split Tensile Strength: Fig. 3 present the variation of split tensile strength, of M20 and M40 concretes containing natural sand (NS) as fine aggregate, with maximum size of aggregate (MSA) while Fig. 4 depict the same for concrete with foundry sand (FS) as aggregate. Split Tensile Strengths measured at 3, 7 and 28 days of curing, in respect of M20 and M40 concrete mixes, are found to increase with decreasing size of fine aggregate. Optimum strength was measured in mixes of 0.6mm MSA in all the mixes considered, irrespective of the type of fine aggregate. As size of aggregate decreased from 4.75mm to 0.60mm, 28-day Split tensile strength of M20 and M40 concretes respectively increased from 2.0 - 2.31 MPa (15.5%) & 2.0 - 2.38 MPa (19.0%) with NS and from 3.12– 3.52 MPa (12.8%) & 3.24–3.64 MPa (12.4%) with FS. As it could be seen, 28-day indirect tensile strengths are higher in mixes made of foundry sand than those of natural sand by 52.38% and 52.94% in M20 and M40 grades respectively.

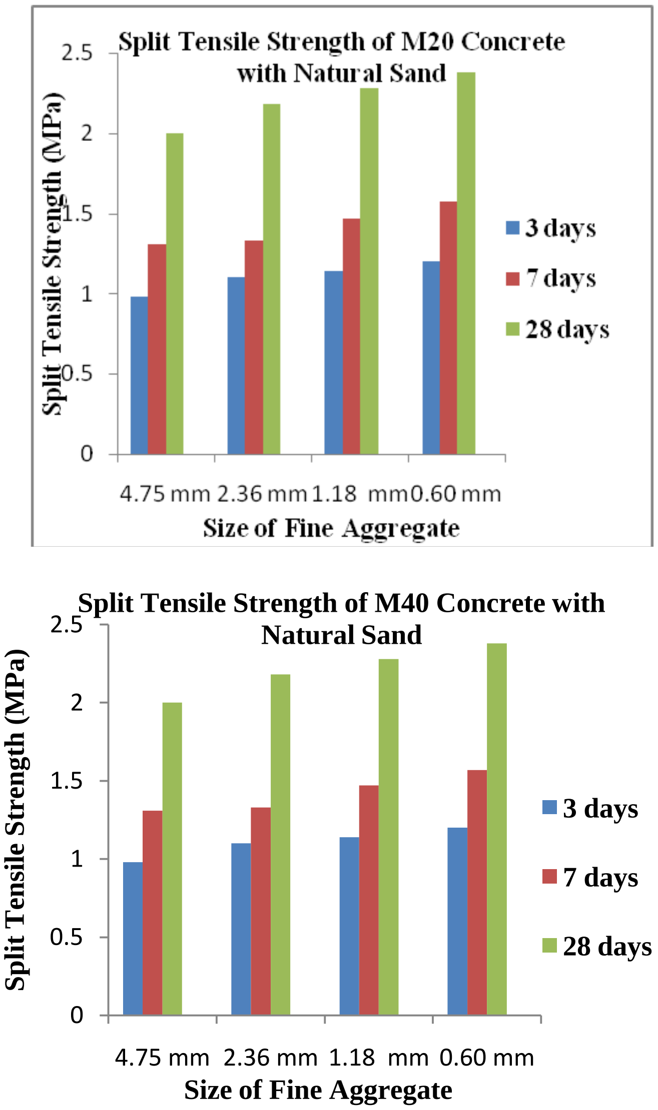
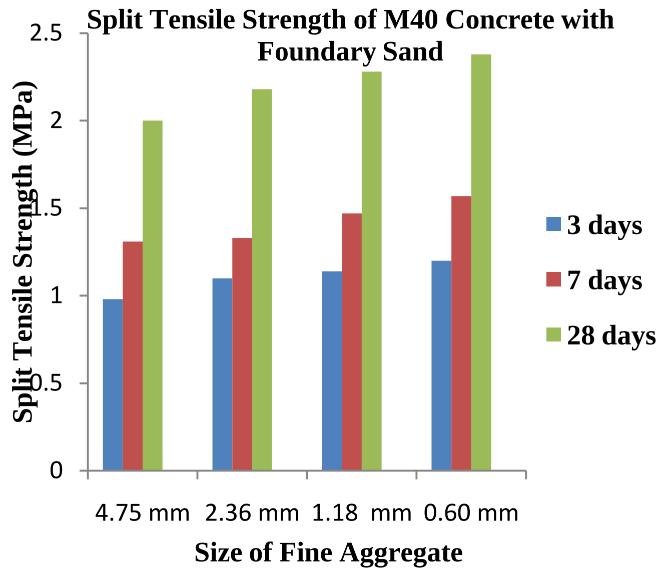


Figure 3. Variation of Split Tensile Strength with size of Fine aggregate (NS)



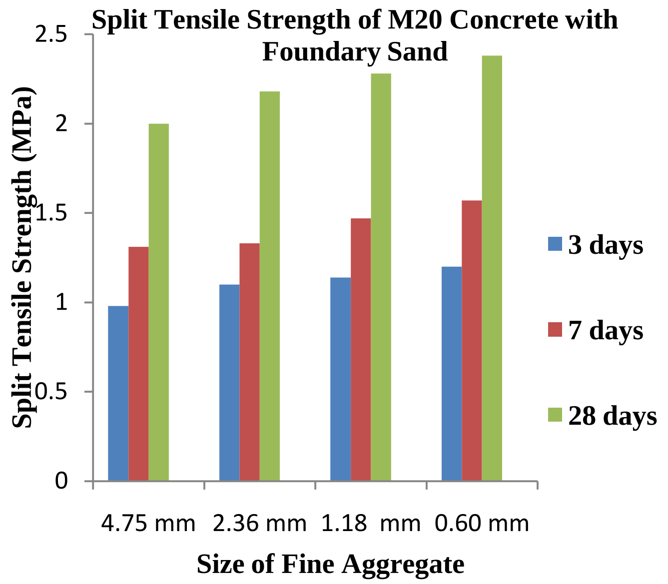


Figure 4. Variation of Split Tensile Strength with size of Fine aggregate (FS)

Flexural Strength: Fig. 5 depicts the variation of flexural strength of M20 and M40 concretes with maximum size of aggregate (MSA) for mixes of two types of fine aggregate namely natural sand (NS) and foundry sand (FS). 28-day flexural strength of M20 and M40 concretes could be seen to increase with reducing maximum size of aggregate (MSA). Flexural strength followed the similar trend of Compressive and tensile Strengths and measured maximum value of modulus of Rupture for mixes of Foundry sand. Moreover, results also showed higher values of modulus of rupture in the mixes containing Foundry sand (FS) than those of with Natural sand (NS). With size of aggregate decreasing from

4.75mm to 0.60mm, 28-day flexural strength of M20 and M40 concretes respectively increased from 1.23 – 1.42 MPa (15.45%) & 1.29 – 1.43 MPa (10.85%) with NS and from 1.86 – 2.03 MPa (23.66%) & 1.90 – 2.10 MPa (10.53%) with FS. Thus, Modulus of rupture is higher in mixes made of foundry sand than those of natural sand by 42.96% and 46.85% in M20 and M40 grades respectively.

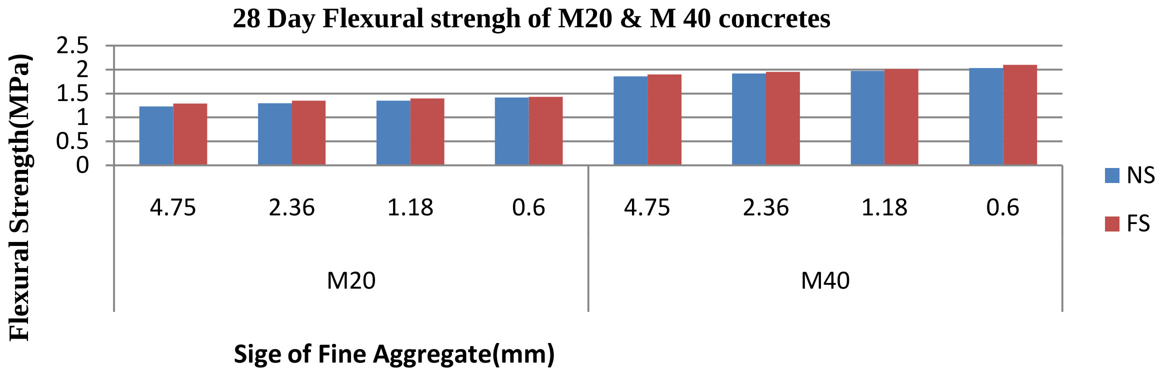


Figure 5. Variation of 28-Days Flexural Strength with size of Fine aggregate

Sorptivity: Fig. 6 shows the variation of Sorptivity, of M20 and M40 concretes with maximum size of aggregate (MSA) for mixes of two types of fine aggregates namely natural sand (NS) and foundry sand (FS). Water sorptivity measured at 3, 7 and 28 days of curing, in respect of M20 and M40 concrete mixes, is found to decrease with decreasing size of fine aggregate and also decreased with progressing age of concrete. Optimal sorptivity was obtained in mixes of 0.6mm MSA in all the mixes considered, irrespective of the type of fine aggregate. Mixes of foundry sand exhibited better performance in sorptivity test than those of Natural sand. But, there is no considerable change in the sorptivity, of concrete containing Foundry sand in comparison to that of Natural sand, in both M20 and M40 grades.

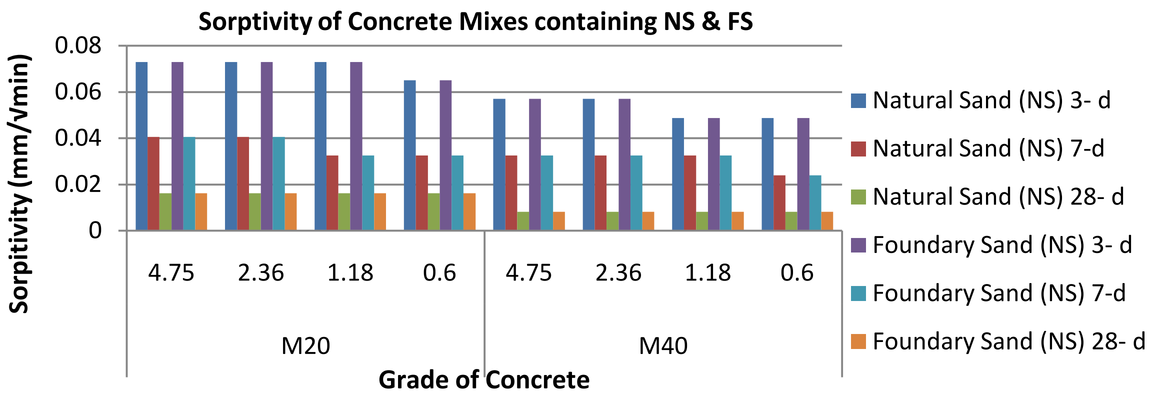


Figure 6. Variation of Sorptivity with size of Fine aggregate (NS & FS)

Ultrasonic Pulse velocity (UPV)

Table. 3 presents the variation of UPV in km/sec, at different ages, for specimens of M20 and M40 concretes made of Natural and Foundry sands. All the pulse velocity values possess good concrete quality grading as per IS: 13311-1992 (Part-1) [15]. The pulse velocity values of concretes tested are in the of range of 3.5- 4.5 Km/sec confirming "good quality" concrete and followed similar trend of strength and sorptivity test results.

Table 3: Ultra sonic pulse velocity (UPV) of Concrete Mixes

Mix	MSA (mm)	Average UPV (Km/Sec) for mix with NS			FS		
		3- d	7-d	28-d	3- d	7-d	28- d
M20	4.75	3.56	3.75	3.91	3.58	3.78	3.96
	2.36	3.35	3.79	3.96	3.46	3.80	3.98
	1.18	3.48	3.87	3.99	3.60	3.83	4.01
	0.60	3.58	3.90	4.03	3.63	3.89	4.07
M40	4.75	4.09	4.12	4.23	4.10	4.14	4.23
	2.36	4.04	4.14	4.26	4.08	4.12	4.26
	1.18	4.11	4.16	4.28	4.11	4.18	4.28
	0.60	4.12	4.18	4.29	4.12	4.20	4.29

4. CONCLUSIONS

- Workability decreased with decreasing size of aggregate, irrespective of the type of fine aggregate, in ordinary and standard grade concretes studied. Concrete mixes with natural sand exhibited better workability than those with foundry sand.
- Compressive strength, tensile strength and modulus of rupture increase with decreasing size of aggregate, irrespective of the type of fine aggregate used in concrete making. But, increase is marginal in Compressive strength and moderate in tensile and flexural strengths.
- Optimum strengths were attained in mixes with 0.60 mm size aggregate, lowest of the particle sizes considered in the study. This is due to the fact that finer size particles contribute to denser packing and result in more durable and less water absorbing concrete.
- Sorptivity decreases with decreasing size of aggregate, irrespective of the type of fine aggregate used in concrete making and optimal sorption is found in mixes with 0.60 mm size aggregate, smallest of the sizes considered.
- There was no considerable change in the sorptivity, of concrete containing Foundry sand in comparison to that of Natural sand, in both M20 and M40 grades.
- UPV values of M20 and M40 concretes produced with natural and foundry sands are in the range of 3.5- 4.5 Km/sec confirming "good quality" concrete.

The overall test results revealed that foundry sand can be utilized in concrete mixtures as a good substitute of natural sand.

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