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Mechanical properties of concrete by replacement of fine aggregate with desert sand

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ABSTRACT

In this research study, the mechanical characteristics of concrete were investigated by substituting desert sand as fine aggregate. Desert sand obtained from Tharparkar was used in five different proportions (0%, 25%, 50%, 75%, and 100 %,). Several tests were carried out to understand the behaviour of concrete made with desert sand as a fine aggregate substitute including those for gradation, chemical composition, slump, density, water absorption, and compressive and tensile splitting tests. The grain size distribution analysis of desert sand revealed that it contains particles with a size of 0.45 mm, and the water absorption of desert sand concrete was found to be 1% higher, whereas workability fell by 6%. The compressive and tensile strength of a concrete mixture containing 75% desert sand was found to be 9.5% and 16.4% respectively higher than nominal concrete made with hill sand, and the average strength rise was on 3.5% and 2% respectively. Substitution beyond 75% was not given desirable results due to the fineness of desert sand. All the test results show that 75% substitution of desert sand as fine aggregate can be used in concrete production under designed concrete standards.

1. Introduction

Concrete as a building material is extensively used all over the world in the construction industry. The current rapid economic growth, rapid urbanization and high demand for construction activities are driving up demand for construction material [1]. All constituents of concrete are locally available, of which aggregates are most important materials. Aggregates in concrete contain substitutes like sand and gravel, they characterize the grain skeleton of concrete, and all the voids inside this skeleton are filled with binding material. The aggregate was originally regarded as an inactive material, but its properties show reactions when combined with other materials, and it also greatly affects the durability and structural performance of concrete. Hill sand or natural sand from riverbeds is being replaced and used as fine aggregate in concrete, and its consumption has been increasing for the few years due to the high rate of concrete production. But increasing extraction of hill sand and natural sand from the bed of rivers triggers many problems like lowering the underground water table, destroying the aquatic life, disturbing the tectonic plates in the distribution of seismic effects, changing the profile of river beds, and continuing mining of river sand results in impure water in the river sand, h leads to an environmental disaster [1]. Soil washed sand was also used as substitute of fine aggregate and achieved target strength of M25 grade though compressive strength was decreased by 10% compared to river sand based concrete[2]. Studies show that recycled glass can also be used as fine aggregate in concrete. It is determined that a concrete mix containing 60% crushed glass replaced by the hill sand as fine aggregate will give a significant strength[3]. Workability is reduced when natural riverbed sand is replaced with manufactured sand. The use of manufactured sand as fine aggregate constituent shows 5% increase in compressive strength and a 9% increase in split tensile strength and flexural[4]. It is clear that crushed rock sand can be used because it improved most of the concrete's properties. Moreover, 0.225 KN/mm2 was found to be the average compressive strength, whereas 0.235 KN/mm2 was the peak compressive strength achieved by the replacement of 20 precent river sand. The indirect tensile strength slightly increased from 1.28 to 1.42 N/mm2 with a 20 % replacement of river sand, but the overall 10.1 % rise in strength justified that crushed rock sand can be a constituent of concrete[5]. Tire rubber powder was replaced with aggregate at different percentages of 2.5%, 5%, and 7.5%. It was discovered that up to 2.5% of tyre rubber powder could be used as a partial replacement in fine aggregate [6]. Concrete containing 20% foundry sand as fine aggregate also shown relatively close that of concrete mix, while beyond this proportion strength was decreased by 2.1% due to fineness and presence of clay and dust particles[7]. The studies were carried out to prepare concrete mixes marble dust by replacing fine sand at proportions of 0%, 25%, 50%, and 100%. Samples were cured for 3, 7, 28, and 90 days and tested for compressive strength. Results have shown that increasing amount of waste marble dust in concrete has also increased the compressive strength of the concrete too. At 100% replacement of fine sand with marble dust, maximum compressive strength is obtained, especially at early curing ages[8]. A Study was carried out on the replacement of fine aggregate with demolished waste concrete. The waste demolished concrete aggregate was added in the place of fine sand with percentages of 0%, 20%, 50%, and 100% , and samples were tasted at curing periods of 3, 7, 28, and 90 days. Results clearly showed that properties of recycled fine aggregate are similar to those of natural sand, and maximum compressive strength was obtained at 20% replacement at 90 days of curing[9].

Class F fly ash has also been used as a partial replacement for fine aggregate. Its mechanical properties showed that by replacing 50% of the fine aggregate with fly ash, it could give maximum strength[10]. Another possible option, apart from hill sand, is the use of desert sand in concrete as a fine aggregate in Pakistan. As in Pakistan, district Tharparkar of province Sindh, with a total area of 19,638 square kilometres, has an enormous amount of desert sand that is not even being used within that area for construction work due to ignorance about its characteristics. No research work is carried out on possible replacement of hill sand with desert sand as fine aggregate in Pakistan. Although, for the RC construction in Tharparkar, people buy hill sand for use as fine aggregate in concrete from faraway areas such as Nooriabad, Jamshoro, and Thatha, which leads to a higher cost. The use of desert sand within and near Tharparkar district will result in lower overall construction costs. This research is aimed at studying the properties of concrete prepared by the replacement of hill sand with desert sand as fine aggregate.

2. Experimental Program

2.1 Materials

Two types of sand, desert and hill sand as shown in Fig. 1 and 2, are used as fine aggregate to investigate their effects and properties on concrete. Both sands are then carried out for sieve analysis as per ASTM C-136 [11]. Sands are sieved on sieves ranging in size from 0.595 mm to 0.074 mm and placed on a sieve shaker, which is vibrated for 10 minutes for proper grading. The particle size distribution obtained for both hill and desert sand is given in Table 1. According to results, desert sand is much finer than hill sand. Fig. 3 depicts that while desert sand contains particles up to 0.45 mm in size and no particles larger than that, while hill sand is well-graded, having particles ranging in size from 0.08 to 1.6mm. According to BS, the fineness modulus varies with the type of sand; greater values indicate coarser sand. If we compare the results as per the BS grading requirement, it is evident that desert sand is fine by nature, and has less fineness modules, which lie in the BF-S column of Table 1, that range from 2.2 to 2.6. While hill sand that has fineness of 4.2 behaves like coarser sand in nature. The size of particles in desert sand is smaller, and furthermore, the texture of desert sand is smoother compared to hill sand or natural river bed sand.

Fig. 1. Desert sand

Fig. 2. Hill sand

Table 1

Sieve Analysis of Hill and Desert sand

Sieve size (mm)	Cumulative Passing %	Cumulative Passing %	BS Grading Requirement		
	Hill Sand	Desert sand	BS-C	BS-M	BS-F
4.75	100	100	89-100	89-100	89-100
2.38	90	100	60-100	65-100	80-100
1.19	74	100	30-90	45-100	70-100
0.595	57.6	100	15-54	25-80	55-100
0.42	49.8	100	NA	NA	NA
0.297	40.8	99.9	15-40	5-48	5-70
0.149	14.6	29.6	0-15	0-15	0-15
0.105	5.6	1.4	NA	NA	NA
0.074	5.5	1.3	NA	NA	NA
F.M	4.6	2.6	2.9-3.2	2.6-2.9	2.2-2.6
W.A (%)	21	23.2			

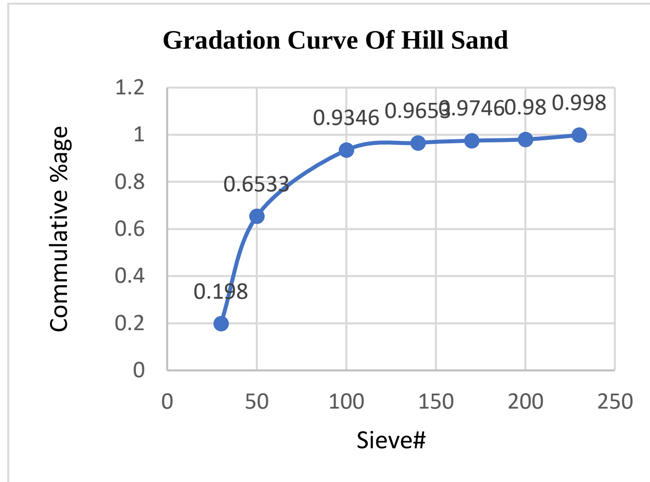

Fig. 3. Gradation of hill sand

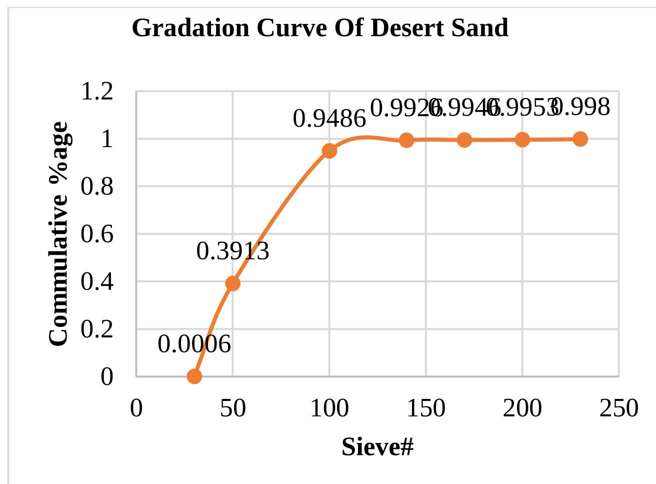

Fig. 4. Gradation of desert sand

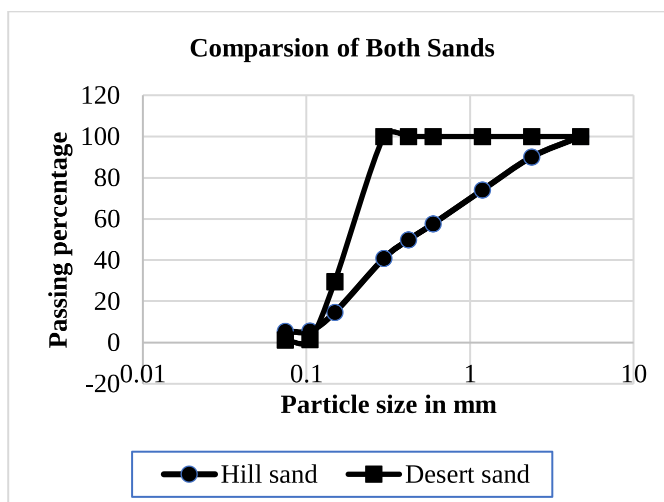

Fig. 5. Comparison of hill and desert sand

In all experimental work, ordinary Portland cement type I in line with ASTM C-150 is used because cement acts as a binding material in concrete. The maximum size of 12 mm was chosen for crushed coarse aggregate that was retained on sieve #4 after passing through ½-inch sieve. In saturated-surface dry (SSD) conditions, coarse aggregate was used; the aggregate was washed and cleaned of clay and organic contaminants.

2.2 Chemical Composition

Additionally, Energy Dispersive X-ray Spectroscopy (EDS) was performed to determine the chemical composition of both hill and desert sand. It can be shown from Table 2 that both samples of sands contain same amount of silicon. Because the chemical composition of Silicon, and its inertness and hardness play a crucial function and resistance, and it is also known as quartz.

Table 2

Chemical composition of Hill and Desert sand

Chemical Components	Hill Sand (%)	Desert Sand (%)
SiO_2	76.51	71.19
Al_2O_3	7.88	11.93
CaO	7.46	6.33
FeO	4.26	3.43
K_2O	2.04	2.53
MgO	1.84	1.59
Na_2O		2.93

2.3 Mix Proportions

Five mixes were prepared, each of which has varying proportions of desert sand in fine aggregate; replaced by hill sand. In all mixtures, the mix design ratio and water cement ratio were kept at 1:2:4 and 0.55, respectively. Desert sand was substituted for hill sand in the amounts of 0%, 25%, 50%, 75%, and 100% as fine aggregate Table 3 provides descriptions of various proportions.

Table 3

Mix Proportion

Mix ID	Cement	Fine aggregate		Coarse Aggregate	Mix Design Ratio	W/C Ratio
	(%)	Hill sand (%)	Desert sand (%)			
M1	100	100	0	100	1:2:4	0.55
M2	100	75	25	100	1:2:4	0.55
M3	100	50	50	100	1:2:4	0.55
M4	100	25	75	100	1:2:4	0.55
M5	100	0	100	100	1:2:4	0.55

3. Testing Procedure

According to ASTM C-136, grading of hill sand and desert sand is done to determine the particle size distribution of both materials as per ASTM C-136[11]. All concrete mixes were tested for slump according to the ASTM C-143 specifications[12]. Fresh concrete was subjected to a density test by following ASTM C-138/C-138M [13]. The Cylinders 100 mm x 200 mm in size were used. For each mixture, tests were run five times and the average of results is being used. Cubes of 100 mm x 100 mm x 100 mm were used as test specimens for the water absorption procedure, which was carried out in accordance with ASTM C-642[14]. The compressive strength test was performed in accordance with ASTM C-39/C-39M[15]. The ASTM C-496/C-496M recommended splitting tensile strength test was performed[16]. The specimens utilized in both tests were cylinders with dimensions of 100 mm by 200 mm. five specimens from each mix were made for each test, and the average result of five specimens was evaluated at 28 days of curing age. The curing period of 28 days was selected, as at 3 days of curing, concrete achieves only 50% strength, whereas from 7 to 14 days it reaches to 80-90% [17], and achieves 99% strength after 28 days, after this curing age there is no significant change in compressive strength until admixtures are utilized[18]. It is also investigated that an increase in curing age improves uniformity and surface texture of concrete [19].

4. Results and Discussion

4.1 Water Absorption Test

By measuring the increasing weight in the concrete specimen, the water absorption test is used to evaluate the rate of absorption of water in the concrete. The specimens ware baked at a temperature between 100 °C and 110 °C following a 24-hour curing period. On average five cubes were collected from each of the five mixes after oven drying. Result from Fig. 6 revealed that increasing desert sand from 0% to 100% has increased the water absorption from 3.70% to 4.70% respectively. For a given consistency, very fine or angular grains require more water [20] and desert sand has more fineness than hill sand and, because of the presence of dust and clay particles, it absorbs water at a somewhat faster pace than hill sand.

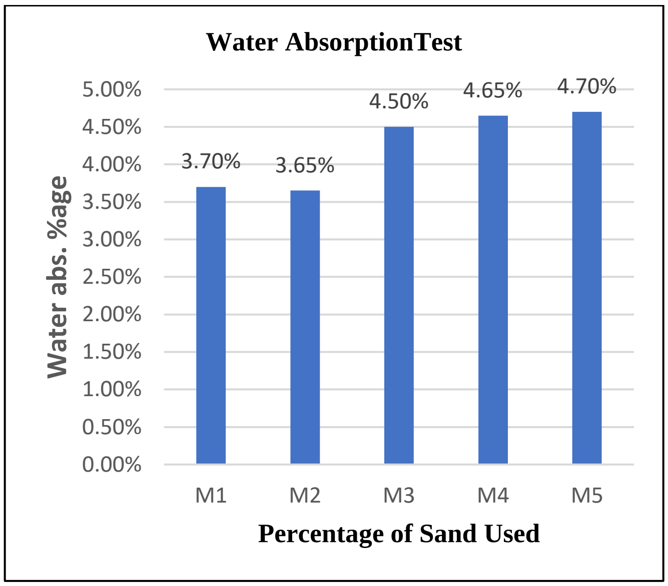

Fig. 6. Water absorption test

4.2 Slump Test

The slump test was used to assess concrete's workability at different proportions of both sands, and their results are displayed in Fig. 7. As we know, the workability of concrete depends on the fineness of the material, and desert sand has a high rate of water absorption compared to hill sand as seen in Fig. 6. Fig. 7 reveals workability of concrete in terms of slump value, it decreases significantly as the amount of desert sand in concrete increases. As it is seen that, M4 mix is less workable than M1 mix, although M2 and M3 representing very close slump values.

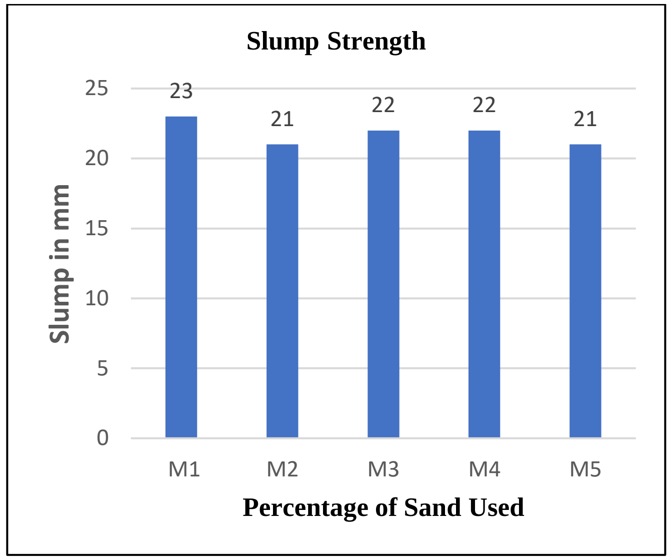

Fig. 7. Slump test

4.3 Density

Fig. 8 highlights the results of the density of concrete made with hill and desert sand. It demonstrates that concrete's density decreases as the amount of desert sand rises. The (M1) made with hill sand has the highest density, while M5 made with desert sand has the lowest density around 2.14% less dense than M1 made with hill sand. The findings show unequivocally that desert sand has little to no impact on the density of concrete.

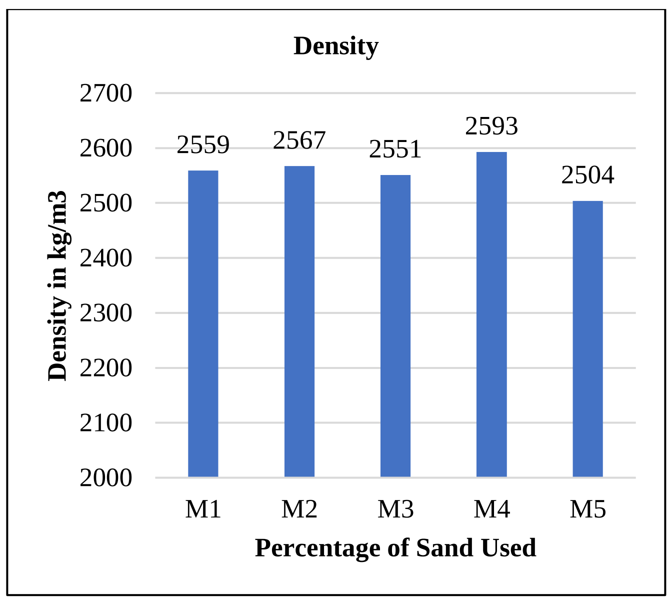

Fig. 8. Density test

4.4 Flow Test for Mortar

The flow test of mortar is performed to analyse the flow behaviour of cement-sand paste. Various trials of standard flow test for mortar were performed at different w/c ratios according to specification of ASTM C-1437 [21]. Mortar made with both desert and hill sand has been tested to compare the flow of concrete. As we increase the desert sand percentage in the mortar, it tends to reduce the flow. Fig. 9 shows clearly how about the flow phenomenon.

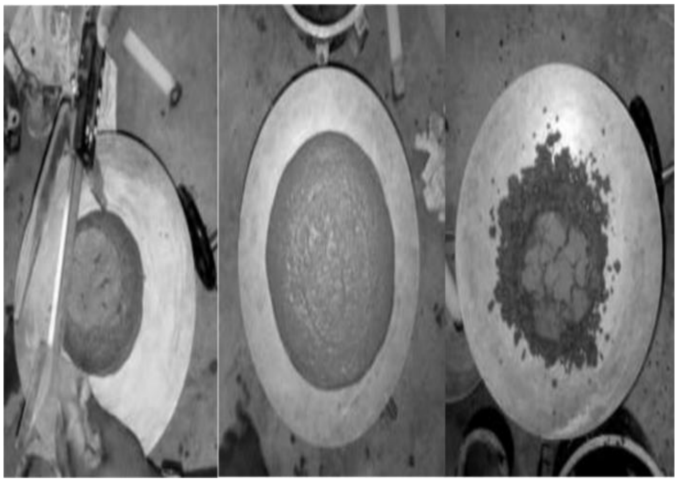

Fig. 9. Flow mortar test

4.5 Compressive Strength and Splitting Tensile Strength Tests

Compressive strength test was conducted by using an Automatic compressive testing machine, while the splitting tensile strength was determined by a Universal testing machine (UTM) as shown in Fig. 10 and 11.

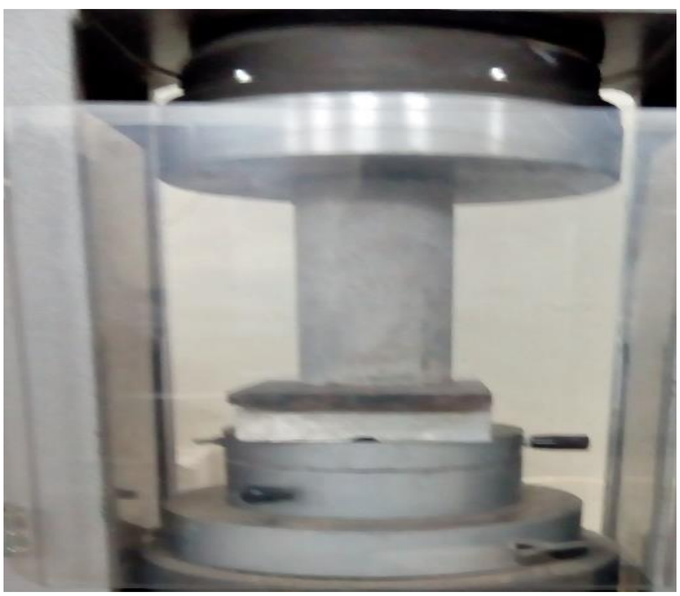

Fig. 10. Compressive test

Fig. 11. Splitting tensile test

The Compressive strength of a concrete mixture containing 75% desert sand was found to be 9.5% higher than nominal concrete made with hill sand, and the average strength rise was on 3.5%. When the concrete was substituted with 100% desert sand, the average compressive strength was decreased by 18.7% as shown in Fig. 12. Tensile splitting strength of concrete mixture prepared with 75% desert sand was found to be 16.3% greater than nominal concrete made with hill sand, with an average strength increase of 2%. With the substitution of 100% desert sand in concrete, the average tensile strength was decreased by 5.2% as seen in Fig. 13. Desert sand has a smoother texture than hill sand, when load is applied, bonding between particles tend to reduced because the particles may slide over one another. In addition, fineness and presence of dust and clay also decreases the strength[7]. Furthermore, desert sand is less abrasive than hill sand, as seen in the M4 mix where 25% hill sand is used, which shows higher strength because this sand holds the particles tight together and resists the sliding of desert sand particles due to its resistive texture and size. All the test results show that 75% substitution of desert sand as fine aggregate can be used in effective concrete production under designed concrete standards. Substitution beyond 75% is not good due to the fineness of desert sand and the presence of dust and clay particles.

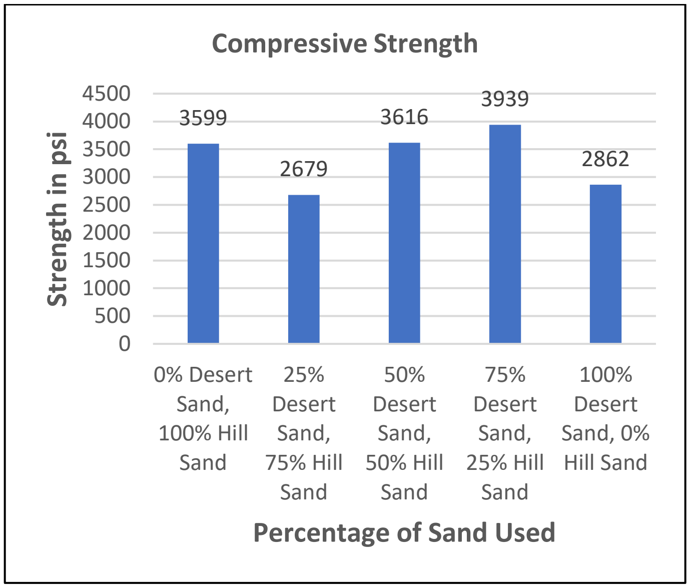

Fig. 12. Compressive test

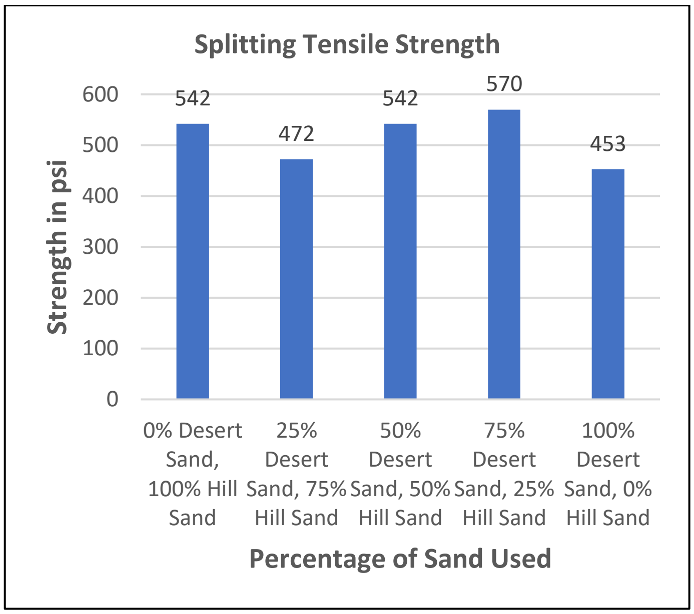

Fig.13. Splitting tensile test

The strength parameters and their changes are clearly displayed in the Fig. 14 comparison graph. Overall, it is apparent that there has not been a significant change in concrete strength; nonetheless, desert sand may be substituted for natural riverbed or hill sand. Due to its enormous existence and high economic value, it will facilitate construction activity and further stops the mining of hill or riverbed sand.

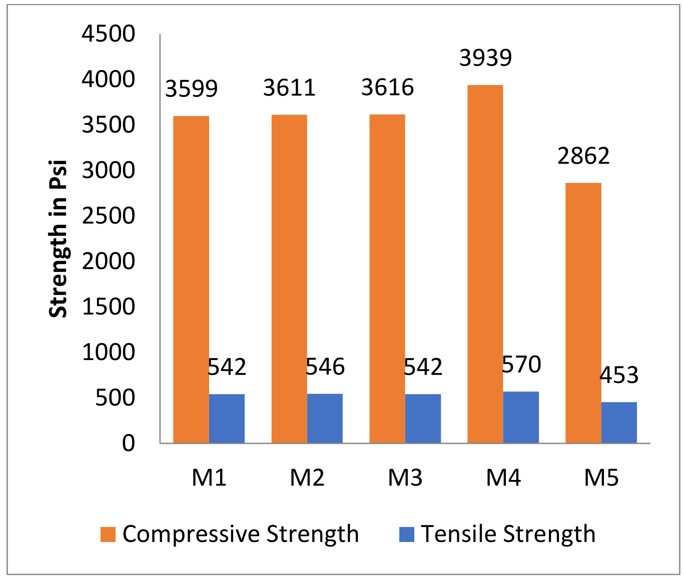

Fig.14. Compressive and tensile splitting strength

5. Conclusion

The following conclusions from experimental investigation based on mechanical properties can be made as follows.

- The maximum compressive strength and splitting tensile strength were obtained at the replacement of 75% of hill sand with desert sand at the curing period of 28 days.
- The workability was found same as hill sand with the increasing percentage of desert sand.
- Water absorption rate was slightly increased by 1% by rising proportion of desert sand.
- The pattern of density remained unchanged, and the effect of desert sand on density is minimal.
- From sieve analysis it was observed that the desert sand is finer than hill sand.
- The SEM-EDS test reveals in the chemical composition that silica content in both sand are nearly identical.
- It is clear from results that desert sand can be used up to 75% as fine aggregate in concrete, above this percentage would not give the desired results.
- The use of desert sand will be more economical in the construction industry, especially to the locals and its use will minimize further extraction of natural sand.

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