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Experimental Investigation on the Effect of Manufactured Sand in Concrete

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Abstract

Concrete is the most widely used construction material owing to its versatile nature. Three fourth of the concrete is made of aggregates, amongst which fine aggregate has massive demand. River sand is the predominantly used fine aggregate, which is under significance because of the increased demand and less availability. The continuous mining of river sand has also affected the environment; ecologically and economically. Manufactured sand offers viable alternative to natural sand, and it is purposely produced by crushing and screening of remains obtained from quarries. Detailed experimental investigation was made on the full replacement of natural sand with manufactured sand as fine aggregate in concrete. The study has been focused on the effect of manufactured sand on mechanical and non-destructive properties of concrete. Mechanical properties such as compressive strength, splitting tensile strength and flexural strength of the concrete were evaluated and compared with control concrete. Also rebound hammer test and ultrasonic pulse velocity test were carried out to have an insight into the quality of the concrete due to effect of aggregate replacement. The test results of this research work implicate that the manufactured sand from various places in concrete had a considerable effect on the mechanical properties of the concrete and the variations of the strength properties of the mixes are explained. The compressive strength based on rebound number was arrived from non-destructive testing results and their correlations were studied.

Keywords: *Manufactured sand, gradation, UPV, dynamic modulus, fine aggregate, strength.*

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INTRODUCTION

Concrete is the most used material in construction industry owing to its versatility. Aggregates comprise of almost thee fourth of the volume of concrete [1]. The use of aggregate influences the concrete properties, both in fresh and hardened state. The effect of fine aggregate size and shape characteristics affect the concrete more than the coarse aggregate [2–3]. Naturally available river sand has been used as the fine aggregate for centuries. The unforeseen improvement in construction has led to a huge demand of river sand, thereby leading to the exploitation of river sand and illegal sand mining. This exploitation of natural materials day by day has paved way for the use of other materials as a replacement for river sand in concrete.

Many researches were conducted with materials such as fly ash, bottom ash, quarry dust, dune sand, etc. [4–9]. The use of fly ash was restricted to 30 to 50% as a replacement for fine aggregate in concrete as they decrease the strength properties, workability and density of concrete on further replacement [6].

The properties of natural aggregate concrete were same as concrete containing bottom ash as fine aggregate up to 30% replacement. It was noted that the presence of bottom ash affected the setting time of concrete [4]. On 10% replacement of quarry dust for fine aggregate, the strength properties were more than conventional concrete, and strength reduced on further addition of dust [10]. Based on the feasibility evaluation it was found that up to 40% replacement of marble dust in concrete is suitable in accordance with the requirements of concrete. Since the conclusion were drawn to use these materials as partial replacement of fine aggregate. So there arises a need for material which can serve as a viable and a complete alternate for river sand. In such progress, manufactured sand is receiving good attention as an alternative [11–13]. Manufactured sand is a produced by processing remains of rock deposits in quarries by crushing, screening and grading to obtain a controlled gradation product [14]. Unlike the dust and ash particles studied, it is cubically shaped and graded with consistency to avoid fines [15].

In this research work, experimental program was conducted with manufactured sand obtained from various places as fine aggregate in concrete. Concrete mixes made with manufactured sand were tested for mechanical properties of concrete and non-destructive testing was done on the concrete specimens, to study their correlation with strength properties.

EXPERIMENTAL PROGRAM

Materials

A 43 grade ordinary Portland cement conforming to specifications of IS 12269-1987 was used in this experimental investigation [16]. Manufactured sands used for the preparation of concrete were obtained from various quarries around Tamil Nadu. The fineness modulus and specific gravity of river sand and manufactured sands are given in Table 1 [17].

The location of the aggregates collected for this study is presented in Figure 1. Locally available crushed granite aggregate of maximum size 12.5 mm, fineness modulus of 5.94 and specific gravity 2.7 was used as coarse aggregate was in conformation with IS 383 -1970 [18]. Potable water obtained from civil engineering department of NIT Trichy was used for the preparation of the concrete mix.

Table 1: *Physical Properties of Fine Aggregates.*

Fine Aggregate	Specific Gravity	Fineness Modulus
RS	2.65	2.35
MS1	2.52	2.63
MS2	2.62	2.01
MS3	2.74	2.53
MS4	2.54	2.81

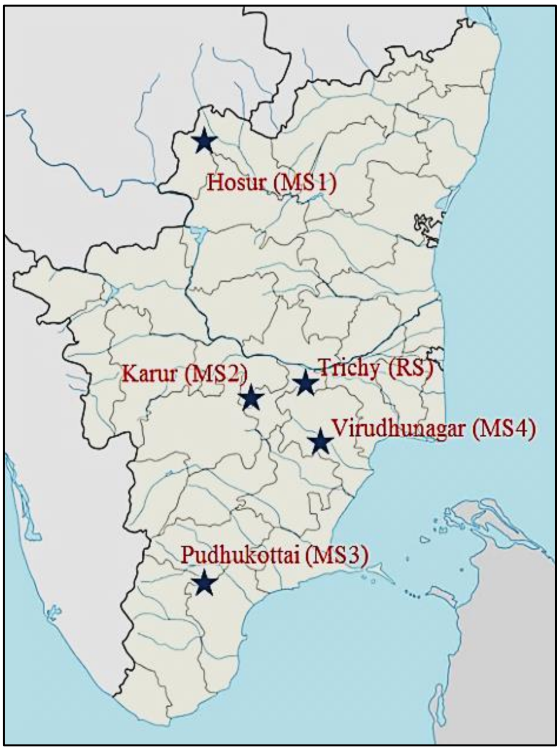

Fig. 1: *Locations of the Aggregates Used.*

Specimen Preparation

The concrete mixes were designed as per Indian Standard Specifications IS: 10262-2009 for M40 grade of concrete [19]. The river sand was replaced by mass by manufactured sand obtained from various quarries. Five mixes were made and mechanical and non-destructive tests were conducted. Detailed mix proportion of the mixes is given in Table 2. All the moulds were properly oiled before casting the specimens. The specimens were removed from the moulds after 24 h and cured in water curing tank for the required age until testing of concrete.

Table 2: *Mix Proportion of Concrete.*

Grade of Concrete	W/C Ratio	Cement	Fine Aggregate	Coarse Aggregate
M40	0.4	1	1.66	2.90

Test Procedure

Cubes, cylinders and beams were casted for compressive strength test, split tensile test and flexural strength test respectively. Test for compressive strength test was conducted at 7 and 28 days of age as per IS: 516-1959 [20]. Split tensile test and flexural strength test were performed after 28 days of curing. Concrete cubes were subjected to non-destructive tests such as rebound hammer test and UPV test before compressive strength test was conducted.

Four mixes were prepared with manufactured sand MS1, MS2, MS3 and MS4 as fine aggregate and designated as M1, M2, M3 and M4, respectively. The results of tests from these mixes were compared with conventional concrete mix made with river sand (RS) as fine aggregate.

RESULTS AND DISCUSSION

Compressive Strength

Figure 2 shows the compressive strength for different mixes. All the mixes except M4 mix were able to achieve more than the mean target strength of concrete for which the mixes were designed and casted.

The mixes M1 and M3 showed reduction in strength of 7% to 5% and 3.5% to 3% in comparison with the control mix M0 at 7 and 28 days respectively. The mix M4 shows the results decrease in compressive strength by 18 and 30% at 7 and 28 days respectively. The deviation in the strength is mainly due to the gradation of the aggregates used. The aggregate MS2 had higher fines content and the lowest fineness modulus, which has led to the increase in compressive strength of the mix M2 with respect to the river sand concrete.

The aggregate with the higher voids and having less amount of fines would lead to an increased need of the cement to occupy the voids. Also concrete made with aggregate MS4 with a fineness modulus of 2.81 which is highest amongst the aggregate used, showed a reduction in compressive strength.

Split Tensile Strength

Figure 3 shows the variation of the tensile strength of various mixes at 28 days. It was found that mix M2 had maximum split tensile strength values and mix M4 had the minimum strength values.

On comparison of the results of the mixes containing manufactured sand with the splitting tensile strength of control mix, the mixes M1, M3 and M4 had results 3.3, 8.7 and 29.2% lower than control mix respectively.

Besides the splitting tensile strength of mix M2 was 7.1% higher than mix M0.

From the results, it can be seen that the reduction in M4 mix was higher than other mixes which showed variation marginally. The replacement of fine aggregates with the same properties did not have a significant variation in strength of the concrete which can be observed in mixes M1, M2 and M3.

This may be due to the surface texture and the shape of the aggregate, as the manufactured sand is formed from fracturing the huge parent rock. So the surfaces of the aggregate were not as smooth as the river sand. Also the sharp cuts of the aggregates might have led to micro cracks formation around its edges while loading.

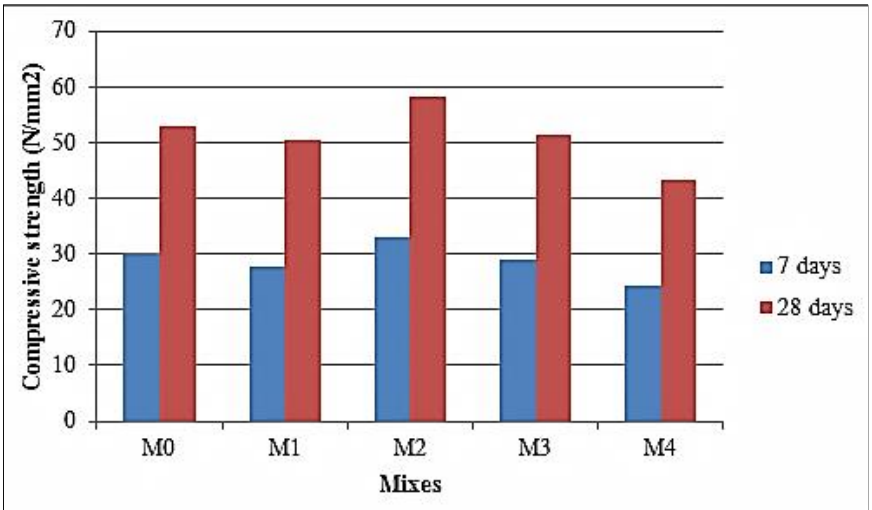

Fig. 2: *Compressive Strength of Concrete Mixes.*

Flexural Strength

The flexural strengths of concrete mixes are graphically represented in Figure 4. The results of M2 mix was higher and results of mixtures M1, M3 and M4 were lower than control mix M0 by 4.7, 0.8, 1.7 and 10.7% respectively. The variation in the results of M0, M1, M2 and M3 were marginally fluctuating, this is due to the similar packing behavior that could be observed based on the gradation of those fine aggregates. The reduction in the flexural strength may be due to the weaker interfacial zone which is due to the rough but angular surface of the MS4 aggregate, thereby the bond of the interfacial zone is weakened.

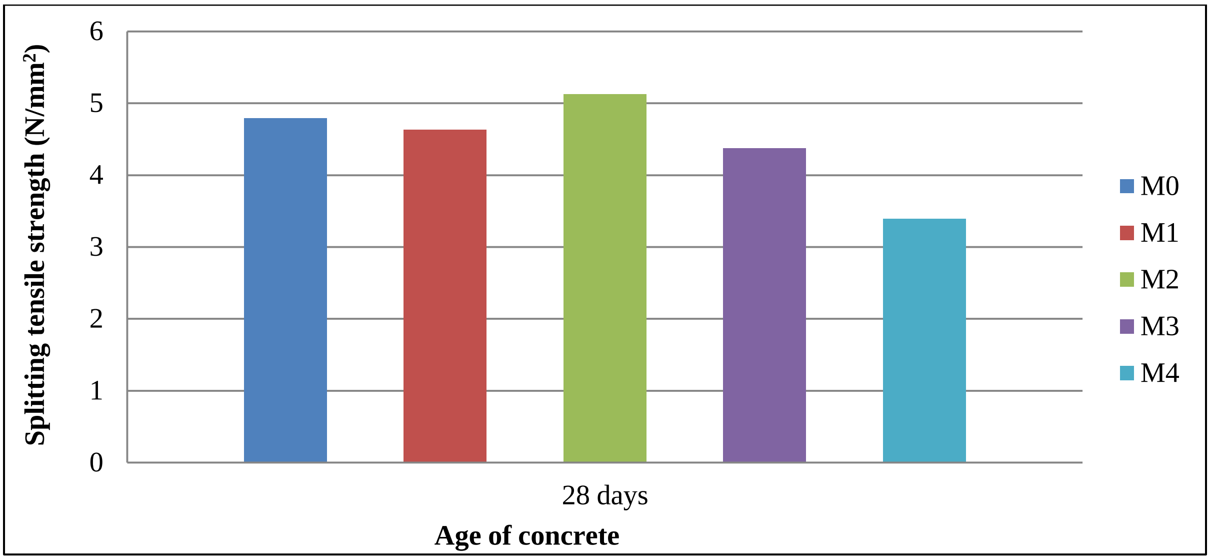

Fig. 3: *Split Tensile Strength of Concrete Mixes.*

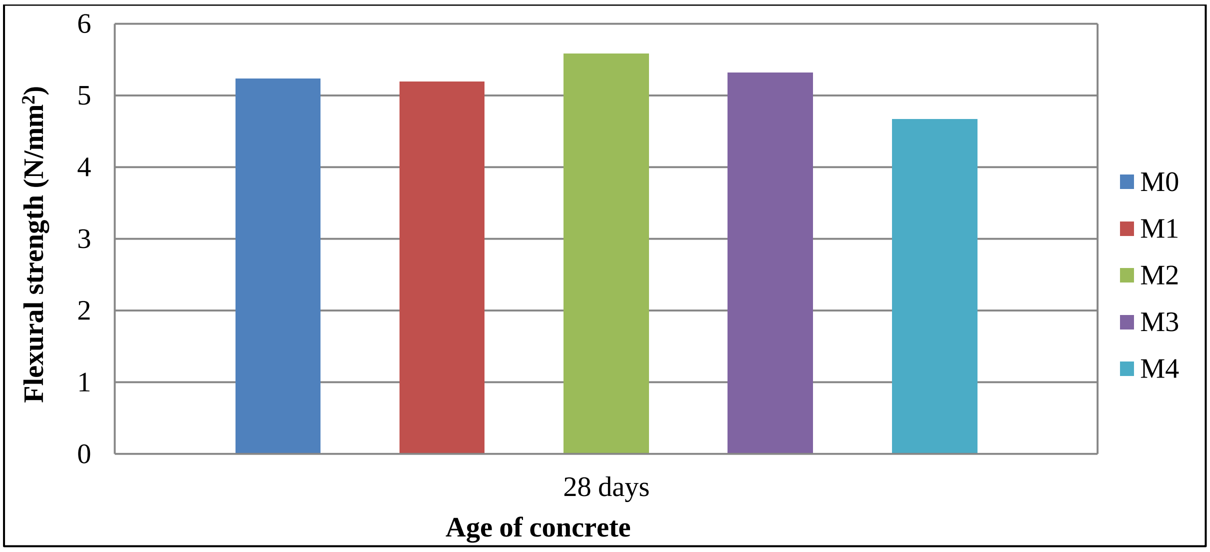

Fig. 4: *Flexural Strength of Concrete Mixes.*

Rebound Hammer Test

The compressive strength of the concrete was assessed based on rebound number as per IS 13311 (Part II) 1992 and presented in Figure 5. The compressive strength based on the rebound hammer number for 7 and 28 days showed a similar pattern as that of the compressive strength properties was observed. The strength estimated using rebound hammer is conservative. But the results of M4 were highly overrated in comparison with the compressive strength of other mixes based on the rebound hammer number obtained. A correlation was made between compressive strength of concrete and the compressive strength based on rebound number as shown in Figure 6.

The following Eq. (1) was obtained from the correlation which had a R^2 value of 0.9382. Since the concrete strength varies exponentially with the age of concrete, the rebound hammer number is not preferable to assess strength of concrete at early age.

$$F_c = -0.0169 f_{crn}^3 + 1.6555 f_{crn}^2 - 50.351 f_{crn} + 509.03 \quad (1)$$

Where,

F_c: Compressive strength of concrete tested experimentally,

f_{crn}: Compressive strength of concrete assessed based on rebound number.

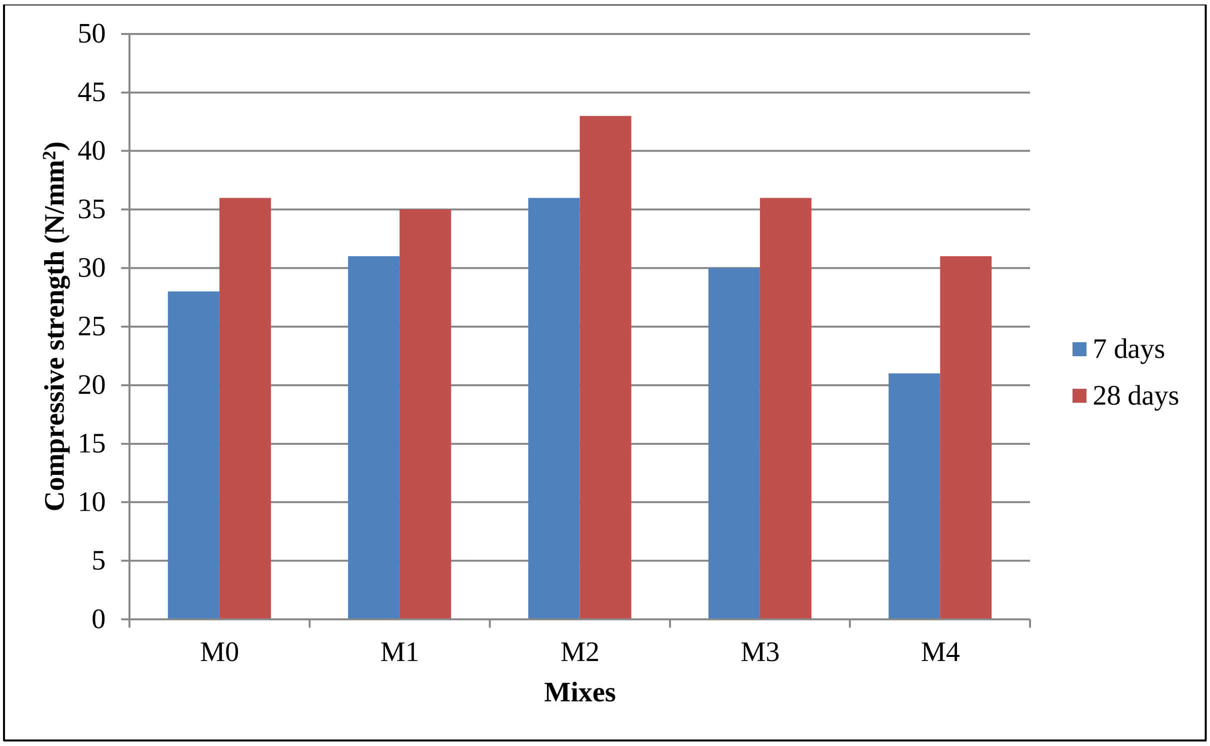

Fig. 5: *Compressive Strength Based on Rebound Number.*

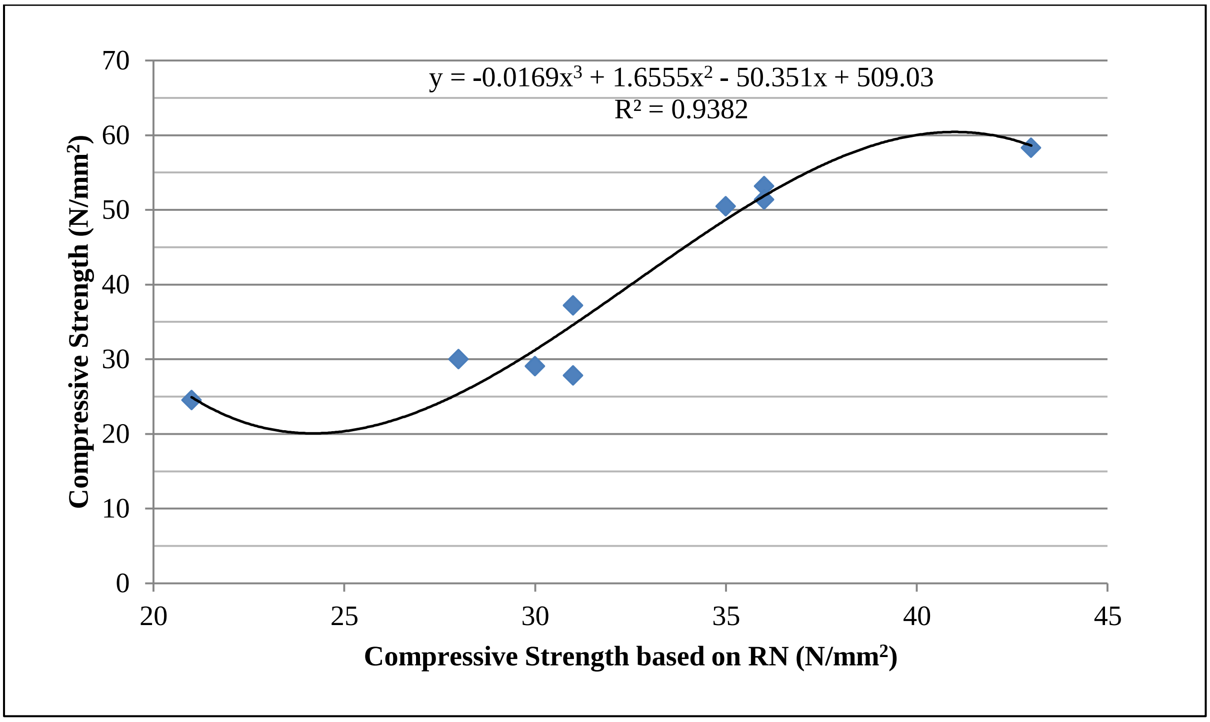

Fig. 6: *Compressive Strength Based on Rebound Number versus Compressive Strength of Concrete.*

Ultrasonic Pulse Velocity (UPV) Test

Figure 7 shows the ultrasonic pulse velocity values of the concrete mixes at 7 and 28 days of age. The results were graded based on the values given in IS 13311 (Part I) 1992. The ultrasonic pulse velocity test results showed the uniform quality of the concrete specimens. M1 mix displayed excellent quality (i.e. UPV >4,500 m/s) at all ages of the concrete. Also UPV results of mixes M2 and M4 specimens at 28 days showed excellent quality of the concrete.

The UPV results of the remaining samples indicated good quality of concrete (i.e. UPV=3,500 to 4,500 m/s). The UPV of concrete mixes increased with age for all mixes implies that the hydration of concrete improves the concrete mix. During the hydration process, the concrete is improved because of the formation of CSH gels which fills the pores thereby improving the velocity.

The dynamic modulus of elasticity of all mixes shown in Figure 8 was calculated based on the following empirical Eq. (2).

$$E = \frac{V_p^2 \rho(1+\mu)/(1-2\mu)}{(1(\mu)} \quad (2)$$

The results of M0 specimens were less in comparison with other mixes at 28 days. Mixes M2 and M4 had dynamic modulus less than mix M0 at 7 days of age. The dynamic modulus results followed a similar trend as seen in UPV test results. The increase in results of mixes with manufactured sand is because the packing of the cement aggregate matrix is dense as they contain more fines than river sand.

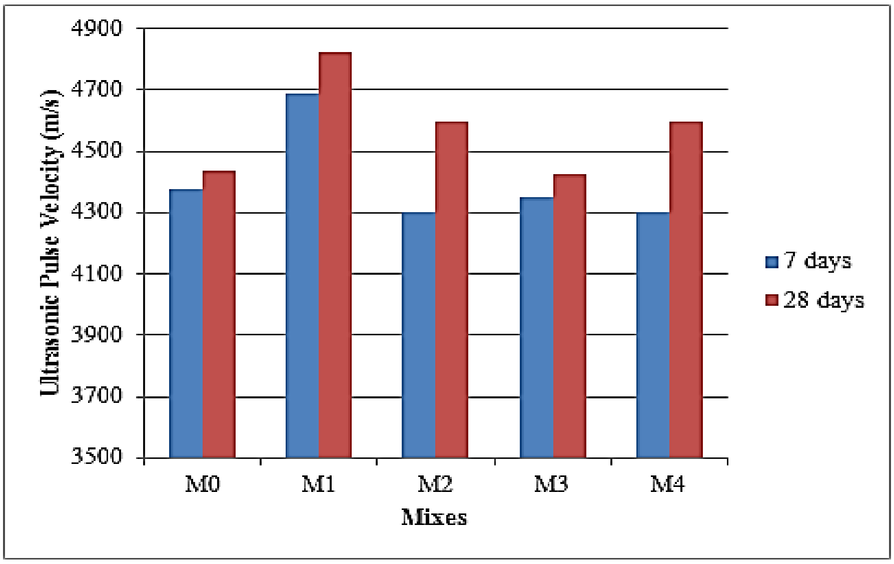

***Fig. 7:** Ultrasonic Pulse Velocity of Concrete Mixes.*

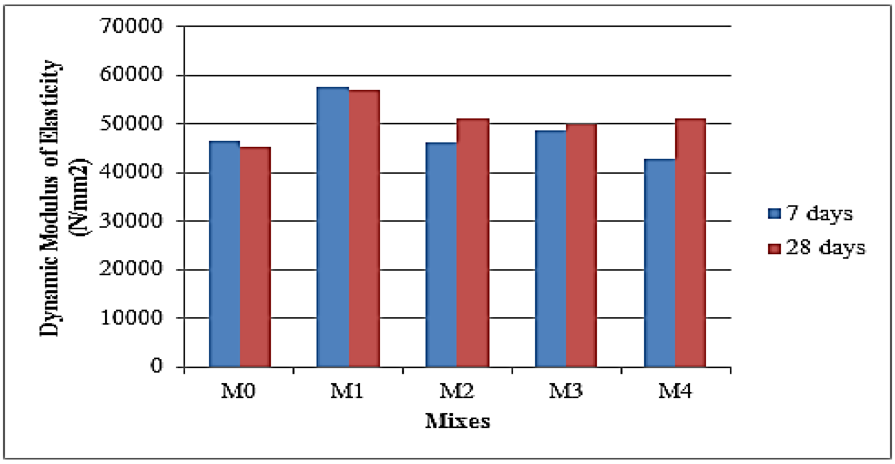

***Fig. 8:** Dynamic Modulus of Elasticity of Concrete Mixes.*

CONCLUSIONS

Based on the experimental investigation conducted in this study with manufactured sand as fine aggregate in concrete, the following conclusions were reached:

1. It was quite evident that the variations in the properties of the concrete mixes were due to the replacement of fine aggregate with manufactured sand.
2. Though variations were observed in the mechanical properties, all the mixes excluding M4 had strength more than the target compressive strength for which the mix design was carried out.
3. Compressive, split tensile and flexural strength were affected by the aggregate properties such as fine content, packing density, surface texture and fineness modulus.
4. The rebound hammer number was able to predict the compressive strength of concrete, though it underestimates the compressive strength; the formula derived would give desirable results.
5. The ultrasonic pulse velocity results show that the quality and integrity of the concrete was good on replacement of manufactured sand as fine aggregate in concrete. Also mix M2 showed excellent quality of the concrete. The improved quality of concrete mixes with manufactured sand was due to the presence of more fines content.
6. Dynamic modulus of elasticity of the concrete with various mixes showed the behavior of the concrete and gave an outlook on the possible development of the microstructure of the concrete.

Hence, manufactured sand is a viable material that has the potential to replace the use of traditional river sand in casting concrete due to its increased demand and also taking into consideration the various economic and ecologic factors.

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