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EFFECT OF STEEL FIBERS ON COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE

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ABSTRACT:

In this research article effect of steel fibers on workability and compressive strength of recycled aggregate concrete is presented. Recycled aggregates from demolished waste were used in equal proportion with conventional aggregates. Steel fibers of 1 mm diameter and 25 mm length were used. For preparation of concrete 1:2:4 mix with 0.55 water-cement ratio was used. Workability of each mix was checked by slump cone test. Total of 40 samples were prepared in standard way and cured for 28 days. All the specimens were tested for maximum load in universal testing machine under gradually increasing load at the rate of 0.5 kN/sec. Recorded load was converted into compressive strength. The obtained results showed that slump of the concrete decreased with increase in the dosage of the steel fibers than conventional concrete. Compressive strength was observed 15% and 34% higher than the compressive strength of conventional and recycled aggregate concrete at the steel fiber dosage of 3%. It is evident that although addition of recycled aggregates in concrete reduces the compressive strength but binary blending with steel fibers not only overcomes this loss but shows strength gain with increase in the dosage of the fibers.

3. INTRODUCTION

Recycling is the action of processing the used material for use in generating new product. The idea of recycling Construction and Demolition Waste (CD&W) was originated after World War II, due to bombarding throughout the period 1939 – 1945 (D. Gao et.al., 2017) in the USA. According to the Environmental Protection Agency's estimation, the annual generation of rubble from construction demolition wastes (CDW) and building renewal is approximately 170 million tons. However, Eurostat reports that the amount of CDW generated in the EU is about 850 million tons, while in the UK alone it is around 110 million tons (L. Sryh & Forth J, 2016). As per the World Bank's survey formulated in the year 2015, some important cities like Delhi and Mumbai in India, are creating a daily waste of about 58,750 kN and 53,900 kN respectively. Generation of daily waste material throughout the entire India stood at 4th place in the world (Gangaram et. al., 2018). For recycling waste material can be obtained from buildings, roads, bridges, and from catastrophes i.e., war, earthquake, or any other natural disaster. To deal with waste concrete reasonably, it can be used to produce recycled aggregate concrete (RAC), which resolve the environmental problem caused by waste concrete and has high economic, social, and environmental benefits (Su Q, 2020). The construction industry is inherently not eco-friendly, and sustainable construction methods are essential to ensure that natural resources are not depleted for future generations. In response to the recent global construction boom, there has been an increased use of natural aggregates in the construction industry. More than 26.8 billion tons of natural aggregate per year are utilized globally (Senaratne et. al., 2016). The usage of natural aggregates is more and more intensify with the advance development in the infrastructure. Reducing the usage of natural resources, energy, and limiting the production of harmful gases is necessary in almost every aspect of life. The concrete industry is a significant contributor to the problem, utilizing a staggering 20 billion tons of aggregates, 1.5 billion tons of cement, and 800 million tons of water each year, while also accounting for 5% to 7% of the world's annual CO2 emissions (Senaratne et. al., 2016). Furthermore, construction waste has been increasing rapidly, necessitating proper waste management practices to address this issue. Dumping such waste in nearby unsuitable areas can cause severe environmental problems. Due to the shortage of dumping sites and increase in cost of transport, most of developed/developing countries are facing problems in handling and discarding of such wastes. By considering all the aspect, it is advisable to reuse the generated waste for productive utilization and to save environment. The waste has been attempted in concrete as replacement of cement, fine and coarse aggregates. But replacement of conventional coarse aggregates with recycled aggregates from demolished waste is more common as coarse aggregates occupies more volume in the body of concrete. Thus, more waste may be utilized which in turn help in saving more conventional aggregates and lessen the waste management burden to some extent.

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Generally, recycled aggregates have higher absorption, abrasion, and lower specific gravity, density, soundness than conventional aggregates. Concrete made with recycled concrete aggregate thus observe deviation in fresh and hardened properties. Some of the techniques to improve compressive strength of recycled aggregates are use of adjusted water-cement ratio, plasticizers, admixtures, additives etc. Many things i.e., fly ash, silica fume, saw dust ash, marble powder, granite and granite powder, glass, ballast furnace ash, coal bottom ash, natural and synthetic fibers etc. have been attempted by different scholars around the globe to improve the fresh and hardened properties of recycled aggregate concrete. But still the research community has not reached widely accepted conclusion. Scatter in the reported results is also a hurdle for adoption of the waste as replacement of conventional ingredients by construction industry and other relevant quarters. It also shows that still more work are required in the field. The use of recycled aggregates in new concrete results in four E's: Ecology, Energy, Equity and Economy (McKay, D. T., 2004).
Steel fibers are one among many other types of fibers which have been attempted in conventional concrete for improvement of its properties particularly the strength properties. The inclusion of steel fibers in conventional concrete significantly improves its post-peak stress and energy absorption capabilities. As a result, steel fiber reinforced concrete (SFRC) has found broad applications in structural engineering. Researchers have extensively studied the mechanical properties of SFRC and have found that while steel fibers contribute little to the compressive strength of concrete (with an increase ranging from 0 to 20%), they can increase splitting tensile and flexural strength by 60% and up to 80%, respectively, with the addition of only 2% steel fibers. Moreover, the inclusion of steel fibers in concrete can increase its modulus of elasticity by up to 30% (Sryh, L., & Forth, J., 2015). These fibers can also be added to recycle aggregate concrete (RAC) to enhance its properties, making it a viable material for use in building construction.

2. LITERATURE REVIEW

Use of recycled aggregates in new concrete as replacement of conventional ingredients of concrete is not new. Good enough time and efforts has been devoted by research community everywhere in the research world. Such efforts have been reviewed by (Memon et. al., 2016) and (Kilani et. al., 2022) separately at different time. The reviews discussed the ways and means of recycling the waste, properties of aggregates, its use in the new concrete, hurdles, deficiencies, and merits. It is mainly argued that scatter in results is main hurdle in adopting the material by industry. Therefore, policies and regulations should be formed and enforced. Also, incentives should be given to the industry for adopting the waste as alternative of conventional ingredients of the concrete. Due to age of concrete, its exposure to various conditions during service life, old cement mortar attached with the aggregates, porous nature, properties of the recycled aggregates deviate from those of conventional concrete. This deviation, particularly water absorption should be considered carefully in the mix design to ensure proper workability and thus least effect on the final strength of product (Abdulla, N. A., 2015).

In a prior investigation, (Memon & Buller, 2016) explored the compressive strength of concrete cylinders using old concrete from Nawabshah City to partially replace natural coarse aggregate. In this study, different replacement percentages of natural coarse aggregates with coarse aggregates from old concrete were investigated, including 0%, 5%, 15%, 25%, 35%, 45%, and 50%. A concrete mix ratio of 1:2:4 and a water-cement ratio ranging from 0.45 to 0.6 were utilized, with the water-cement ratio adjusted to maintain the workability of the concrete due to the higher water demand of the aggregates from old concrete. The authors tested a total of 324 cylinders and found that the maximum strength reduction occurred with 50% replacement of natural aggregates, resulting in a reduction of 26%. The authors concluded that the coarse aggregates from old concrete can be effectively used as a substitute for natural coarse aggregates in areas where the load-bearing capacity of the concrete members is less critical. However, the reported strength loss was slightly higher than the 5-24% range of strength reduction for concrete mixes prepared with recycled aggregates compared to traditional aggregates, as indicated in the ACI 555R-01 report (Lamond, J et. al., 2001).

Researchers have attempted to improve the properties of recycled aggregate concrete by incorporating various types of fibers, including steel fibers. Many studies have investigated the effects of varying the diameter and length of the fibers. Al-Luhybi, (2019) reviewed many of these attempts and argued that while increasing the dosage of recycled aggregates reduces the strength properties of the concrete, the addition of steel fibers improves its compressive, tensile, and flexural strength, as well as reducing drying shrinkage. This suggests that the use of steel fibers has a positive effect on the hardened properties of the concrete, but determining the optimum dosage of the material remains an issue.

Chandar et. al., (2017) used steel fibers in the dosage of 1, 1.5 and 2 percentage along with recycled aggregates to check the effect on compressive strength. Laboratory investigations showed the authors increase (10%) in the parameter at the dosage of 1% of steel fibers which on contrary without steel fibers reduced by 2.36%. Luhar et. al., (2018) instead of steel fibers used steel powder as additive to check its effect on compressive strength of concrete with recycled aggregates in the dosage of 10%, 20%, and 30%. The steel powder was used in the dosage of 2.5% and 5%. Test results revealed increase in compressive strength for all dosage of steel powder at all replacement level of conventional aggregates with recycled aggregates. Also, the material showed better resistance to abrasion. Bhan and Kaur, (2018) also studied the effect of steel fibers on strength properties of recycled aggregate concrete. Recycled aggregates were used in percentage of 50 and 100, whereas the steel fibers of aspect ratio 25 were used in the dosage of 0.5% and 1%. From the test results authors observed 17% increase in compressive strength at 0% replacement of conventional aggregates, 20% increase with 100% RCA plus 0.5% steel fibers, and 9% increase at 100% RCA plus 1% steel fibers. Hence the authors concluded optimum dosage of steel fibers equal to 0.5% and argued that even 100% conventional aggregates can be replaced with recycled aggregates without any reduction in compressive strength. Verian et. al., (2018), based on their research program concluded that addition of steel fibers improves the strength properties even equal to that of conventional concrete. In another research study by Venugopal et. al., (2022), effect of steel fibers (0.5%, 1.0%, and 1.5%) on compressive strength of recycled aggregate concrete (with RCA equal to 50% and 100%) was checked. Laboratory investigations revealed the authors increase in compressive strength at all dosages of steel fibers than conventional concrete but were maximum with 1% of the steel fibers.

In 2021, (Awchat, 2021) aimed to improve the strength properties of recycled aggregate concrete by using steel fibers (0.5%, 1.0%, and 1.5%) and Styrene-Butadiene Rubber (2.5%,

5.0%, and 7.5%). The author tested 198 cubes of M20 and M25 concrete, and found that the addition of 1% steel fibers and 5% polymer led to an 8.62% to 12.57% increase in compressive strength for 28 and 90 day cured samples. The author also observed higher strain values in all specimens with steel fibers, and concluded that the use of polymer in steel fiber reinforced recycled aggregate concrete positively impacts compressive strength, strain characteristics, and bond behaviour between concrete ingredients. Ahmed et al., (2021) also attempted to improve the strength properties of steel fiber reinforced recycled aggregate concrete by using ground granulated blast furnace slag as a partial replacement for cement. Test results showed a 39% improvement in compressive strength at an optimum dosage of 40% RCA, 20% GGBS, and 2.0%. The authors also noted increased split tensile strength, acid resistance, decreased water absorption, and increased crack resistance of the concrete. Omidinasab et al., (2022) used recycled aggregates in dosages of 0%, 25%, 50%, 75%, and 100% and steel fibers in dosages of 0%, 0.5%, and 1.0%. As with other studies, the authors observed a reduction in workability, compressive strength, tensile strength, flexural strength, and impact resistance with the induction of recycled aggregates, particularly at 100% replacement. However, the addition of steel fibers improved these reduced properties. From a cost analysis, the authors observed a 62% and 76% increase in cost due to the induction of RCA and SF, respectively. Furthermore, from a multi-criteria optimization approach, the authors concluded that 50% and 1% are the optimum dosages of RCA and SF, respectively, with respect to the properties and cost of the concrete. Not only the basic properties and strength characteristics of fiber reinforced recycled aggregate concrete have been studied by the scholars, but other parameters like, effect of exposure of fire (Omidinasab et al., 2022), impact resistance (Nazarimofrad et. al., 2017) and bond behaviour (Hameed, 2020) have also been studied.

A thorough examination of the literature reveals that research studies conducted in recent years have explored the impact of fiber addition on the mechanical properties of recycled aggregate concrete (RAC). However, due to the inconsistency in the results, more research is necessary in this area to improve confidence in the findings. Accordingly, the present study aims to evaluate the workability and compressive strength of RAC with varying quantities of steel fiber. The outcomes of this study will not only reduce the need for natural aggregate but also assist in resolving the dumping issue and promote environmental sustainability. Additionally, it will provide an alternative approach to enhancing the strength properties of recycled aggregate concrete.

3. CONCRETE INGREDIENTS

Conventional ingredients of concrete used in this research work are ordinary Portland cement under brand name Pak Land Cement, hill sand, coarse aggregates of maximum 25 mm size, potable water.

The cement was sieved using #100 to check its fineness. The outcome (<20% retained) confirmed the quality of cement in accordance with (ASTM C150/C150M-18). The hill sand and coarse aggregates were obtained from government approved quarries for the material. The sand was sieved as per provisions of (ASTM C136/136M). Percentage passing on various sieves is shown in Figure 1. The fineness modulus of sand was recorded equal to 2.42. The value confirms the material as fine sand as per (ASTM C136/C136M). The conventional coarse aggregates were first sorted for unwanted substances followed by washing and drying in laboratory for 24-hours. The sieve analysis of the fine aggregates (sand) as given in figure 1 was done following the relevant ASTM standards. Grading curves of the coarse aggregates are shown in Figure 2. The fineness modulus of the aggregates was recorded equal to 7.3.

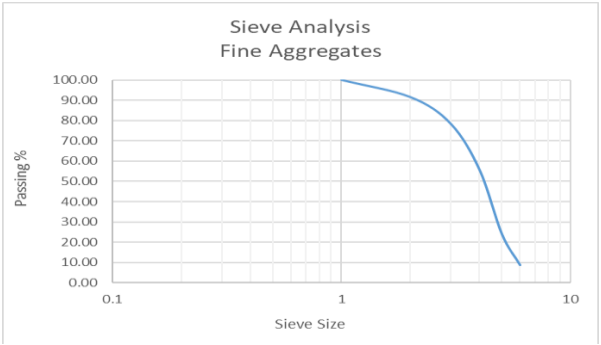


Figure 1. Sieve analysis of sand

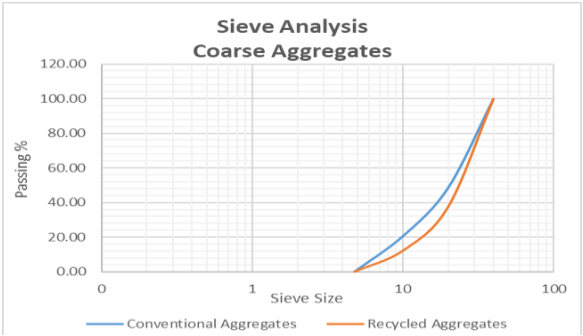


Figure 2. Sieve analysis of coarse aggregates

For recycled aggregates, demolished waste was collected from demolishing of a residential building in Nawabshah city. The large blocks (Figure 3) were brought to laboratory and hammered down to maximum of 25 mm size in line with the size of conventional coarse aggregates (Figure 4). These aggregates were sorted for organic material, cracked particles etc. followed by washing and drying in laboratory for 24-hours. Then sieve analysis of recycled aggregates was done in similar pattern to conventional aggregates. The percent passing on various sieves is shown in Figure 2. The fineness modulus of recycled aggregates was recorded equal to 7.5.



Figure 3. Demolished waste



Figure 4. Recycled coarse aggregates

For steel fibers, steel wire of 1 mm diameter was cut in length equal to 25 mm, thus the aspect ratio of the fibers was equal to 25 (Figure 5). The tensile strength of the steel fibers wase determined and found equal to 260 MPa. The water used for mixing of the ingredients was of city water supply scheme with pH value equal to 6.8.



Figure 5. Steel wire and steel fibers

4. MIX DETAILS AND TESTING

To test the proposed concrete, 1:2:4 mix with water cement ratio equal to 0.55 was used. Higher water cement ratio was adopted considering the water demand of the aggregates from old concrete. Conventional and recycled coarse aggregates were used in equal proportion (50% each) following the recommendations of Oad and Memon (Gangaram et.al, 2018). Steel fibers were used in the dosage of 0.5% to 3% by volume of the specimen. Additionally, one mix was designed with 0% steel fibers but with recycled aggregates. Also, a mix was designed without recycled aggregates and steel fibers. These mixes were treated as control mixes and were used to compare the results of proposed concrete. The details of mixes and specimens are given in Table 1.

S.#	**Mix**	RCA (%)	Cement (kg)	FA (kg)	NCA (kg)	RCA (kg)	Steel fibers (%)	Aspect Ratio	# of Samples
1	CC	0	6.43	12.86	25.71	0.00	0	..	5
2	RAC	50	6.43	12.86	12.86	12.86	0	..	5
3	B1	50	6.43	12.86	12.86	12.86	0.5	25	5
4	B2	50	6.43	12.86	12.86	12.86	1		5
5	B3	50	6.43	12.86	12.86	12.86	1.5		5
6	B4	50	6.43	12.86	12.86	12.86	2		5
7	B5	50	6.43	12.86	12.86	12.86	2.5		5
8	B6	50	6.43	12.86	12.86	12.86	3		5

Table 1. Details of mixes and specimens

A. Slump test

To check the workability of the concrete slump test was performed on each mix following ASTM C143 (Verian et.al, 2018). Concrete ingredients were batched by weight and were mixed in pan mixer till uniform paste was formed. For each mixed detailed in Table 1, slump cone was filled in three layers with 25 blows of tamping rod to each layer.

The top of the cone was levelled followed by lifting the cone carefully and recording the slump value. A test sample is shown in Figure 6. Obtained results are given in Table 2.



Figure 6. Slump test

S. No	Mix	Slump (mm)
1	CC	71
2	RAC	60
3	B1	25
4	B2	30
5	B3	40
6	B4	30
7	B5	30
8	B6	40

Table 2. Slump values

B. Specimen preparation and testing

Following the slump test, concrete cubes of standard size (6"x6"x6") were prepared. The inner surface of cube molds was oiled followed by filling the mold in layers. Table vibrator was used to compact the concrete in molds. After a day the specimens were de-molded and allowed to air dry in laboratory for 24-hours (Figure 7). Then the specimens were cured for 28-day by fully immersing in potable water (Figure 8). After the completion of curing time, specimens were taken out of water and allowed to air dry for 24-hours. All the specimens were then tested for failure load in universal testing machine under gradually increasing load (Figure 8). The failure load recorded was then converted into compressive strength by standard formula. The compressive strength results of all eight batches of the specimens are listed in Table 3.



Figure 7. Concrete specimens



Figure 8. Curing of specimens

Sample	Compressive Strength (MPa)							
	CC	*RAC*	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*
C1	28.4	24.2	25.8	30.2	28.1	30.2	30	34.5
C2	30.4	24.3	25.5	29.6	27.7	29.6	31	32.7
C3	27.7	24.3	24.1	28.6	27.9	29.9	32.7	34
C4	28.9	26.1	25.2	28.1	28.2	30	31	32.3
C5	30.3	24.6	25	26.7	27.4	30.9	31.8	32.6

Table 3. Compressive strength

5. Results and Discussion

The results of slump test conducted on the concrete presented earlier in tabular form are plotted in Figure 9 for visualization and comparison. It may be observed that highest slump value is recorded for conventional concrete. Induction of recycled aggregates affected the results by 15%. Further addition of steel fibers aggregated the loss of slump in fluctuating manner. Improvement in the test values was observed for B3 (1.5% steel fibers) and B6 (3% steel fibers) batches.



Figure 9. Testing of specimens

The flowability of concrete is affected due to presence of steel fibers. As the distribution of the fibers is random in the concrete therefore in case of horizontal and inclined orientation, fibers offer more resistance whereas vertical position affects less. Therefore, improved results for B3 and B6 were observed. The percentile deviation of the slump value for all batches is shown in Figure 10. All the batches of binary blended concrete observed less workability than required for normal concrete hence use of admixture to improve the workability thus maintain the workmanship with the concrete is proposed.

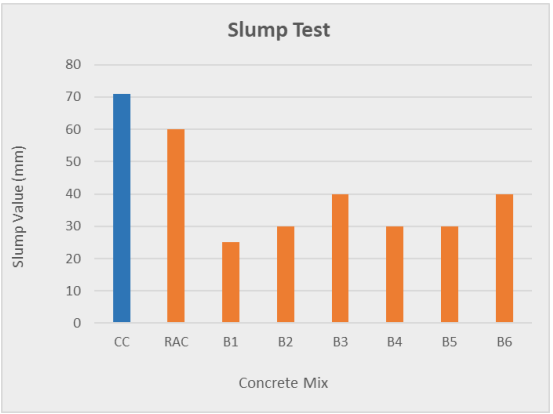


Figure 10. Slump values

Compressive strength computed from crushing load of individual specimens in turn was listed in tabular form in previous section. To compare the results of the proposed concrete with control mix the same is plotted in Figure 11.

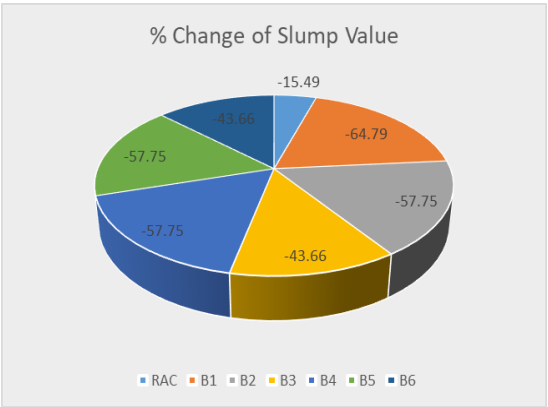


Figure 11. % change of slump values

The compressive strength of B1 to B6 is also compared with concrete with recycled aggregates only in Figure 12. It may be observed from these figures that again induction of the recycled aggregates in concrete reduced the compressive strength. On the other hand, induction of steel fibers in the concrete produced positive effect on compressive strength in terms of increased values. 0.5% dosage of the fibers showed lesser compressive strength than conventional concrete but all other dosages showed improvement in the strength parameter with equal or more values than control mix. The comparison of binary blended concrete with recycled aggregate concrete without steel fibers showed improvement of the results for all dosages. This shows that the fibers present in concrete produces interlocking of the concrete matrix. Figure 13 shows selected specimen hammered further after failure in universal testing machine to observe the internal positioning of the fibers. It not only improves the stress distribution mechanism but also help in increased crack load and bridging of the cracks. Although uniform distribution of the fibers is extremely difficult yet the random distribution produces positive effect on the concrete in terms of compressive strength.

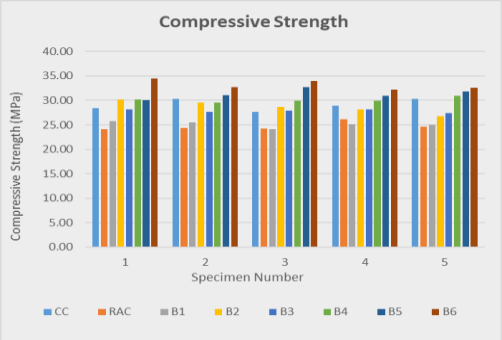


Figure 12. % CS (B1 to B6 vs control concrete)

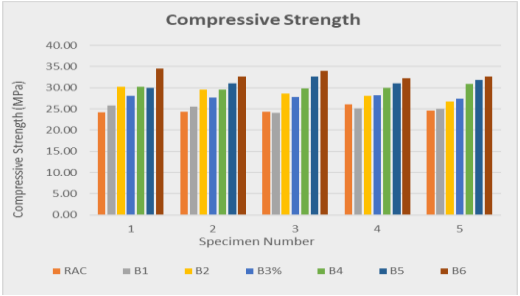


Figure 13. % CS (B1 to B6 vs RAC)

The compressive strength of individual five specimens in each batch was averaged. The obtained results are compared with conventional and recycled aggregate concrete in Figures 14 and 15. Increasing trend of the average compressive strength is evident from these figures except for batch B3 (1.5% steel fibers). It is due to the concentration of fibers in one place. Although the compressive strength of this batch was less compared to conventional concrete but was observed higher than the compressive strength of recycled aggregate concrete.



Figure 14. Fibers in failed specimens

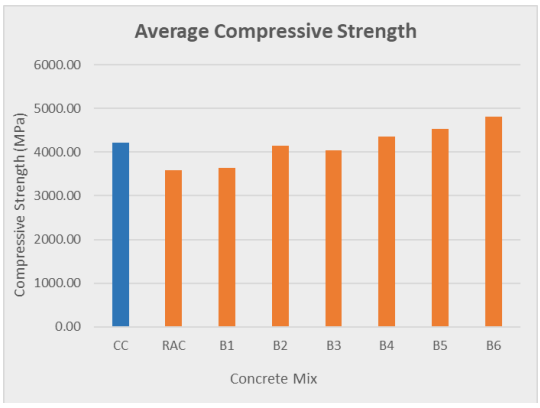


Figure 15. Average CS (CC, RAC & B1 – B6)

The deviation of compressive strength due to addition of steel fibers in conventional and recycled aggregate concrete is shown in Figures 16 - 18. It may be observed from these figures that due to addition of recycled aggregates compressive strength was reduced by 15%. This difference was not affected much due to addition of steel fibers at the dosage of 0.5% but drastically reduced to only about 2% at dosage of 1% and kept on reducing with increase in dosage of steel fibers. At the highest dosage used in this work about 14% higher compressive strength was recorded. Increasing trend of compressive strength may be observed due to steel fibers in comparison to recycled aggregate concrete. All dosages of steel fibers showed higher compressive strength with 34% increase at highest dosage used. It is anticipated that increase in dosage of steel fibers will result in increased compressive strength. However, ductility is another important property of concrete and need to be addressed properly while deciding the highest dosage of the steel fibers.

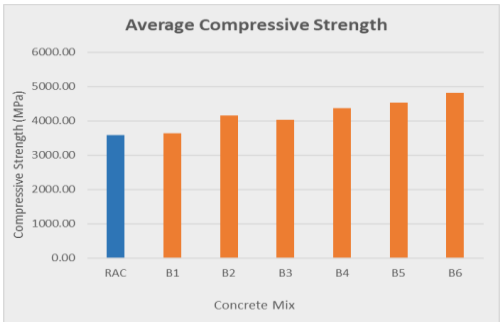


Figure 16. Average CS (RAC & B1 – B6)

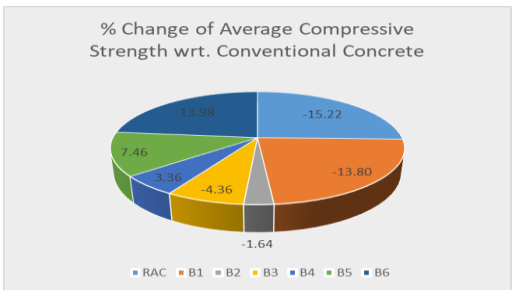


Figure 17. CS deviation than CC

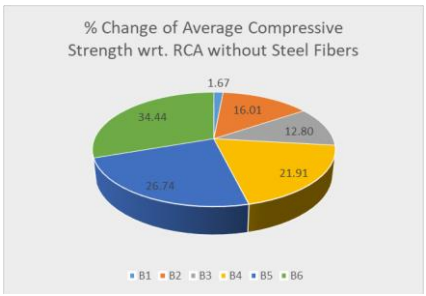


Figure 18. CS deviation than RAC

6. Conclusion

Based on the outcome of laboratory investigations for workability and compressive strength of binary blended concrete with recycled aggregates from demolished concrete and steel fibers following are concluded.

1. Workability of concrete reduced with addition of recycled aggregate and further aggravated due to addition of steel fibers.
2. Orientation of steel fibers in concrete matrix controls the slump flow.
3. Addition of recycled aggregates from demolished concrete negatively impacts on the compressive strength.
4. Addition of steel fibers improves the compressive strength beyond the loss of the strength due to addition of recycled aggregates.
5. 15% increase at 3% dosage of steel fibers of L/D ratio 25 was recorded than the strength of conventional concrete without steel fibers.
6. 34% increase in the compressive strength than the compressive strength of recycled aggregate only concrete was recorded at same dosage and L/D ratio of steel fibers.

7. ACKNOWLEDGMENT

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