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Workability and strength of recycled aggregate concrete reinforced with nylon fibers

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K E Y W O R D S

Demolished Waste Recycled

Aggregate Concrete

Nylon Fibers

Compressive Strength

Sustainable Development

Tensile Strength

A B S T R A C T

The demolishing waste generated due to demolishing of the structures has proved difficult to handle due to scarcity of the dumping space particularly in urban areas. It's use in new concrete solves the problem to some extent but developed product differ in properties both at fresh and hardened state. To overcome the deficiency nylon fibers are proposed in this work.

The compressive and tensile strength of proposed concrete at hardened state and workability as fresh property of concrete are studied. Conventional and recycled aggregates were used in equal proportion. Nylon fibers of 1 mm diameter and 25 mm length were used from 0.25% to 2% with 0.25% increment in each successive batch were used. Using 1:2:4 mix with water cement ratio equal to 0.5, total of 10 mixes were designed. Workability of each mix was evaluated by slump cone test.

Water curing for 28-days was used for five samples in each batch. Compressive and tensile strength were computed from crushing load determined in universal testing machine. Comparison of the results with those of control concrete revealed that 1.5% of nylon fibers along with 50% recycled aggregates produce maximum compressive strength 930.16 (MPa) with 24% more than conventional concrete (24.16 MPa) and 56% more than recycled aggregate concrete (19.27 MPa) without nylon fibers. The tensile strength of the proposed concrete (3.66 MPa) was noticed 22% and 55% higher than the conventional concrete (3.0 MPa) and recycled aggregate concrete (2.36 MPa) at optimum dosage. Hence the impact of optimized doze of the nylon fiber shows improved strength properties of the concrete.

1. Introduction

Concrete is among the most widely used materials in civil engineering applications and other structures around the world. Conventional concrete is a mixture of water, cement, and aggregates. Its fluidity gave the constructors choice of construction of shapes of the desire and made the concrete most versatile and widely used material in the construction industry. However, the energy consumption and its side effects in development of the constituents of cement have negative impacted the environment. On the other side the construction boom around the globe turned into mass consumption of the concrete constituents. Particularly the use of coarse aggregates obtained by quarrying of the rock mountains has alarmed the situation as it seems that if the pace of usage of the aggregates continued will result in scarcity of the aggregates. Also, the new construction particularly in city centres around the world is being carried out by demolishing the short height or old buildings resulting in huge quantum of the construction and demolishing waste. Management of the same due to shortage of the dumping areas is an additional problem and sometime puts heavy financial burden on the project due to transportation of the waste to far areas. Therefore, not only the fear of scarcity of the aggregates but also the management issue of demolishing waste is bi-fold problem. Both quarrying of aggregates to meet excessive use and demolishing waste has adversely affected the environment also.

One of the solutions for this multi-sided issue is the usage of demolishing waste on site. A portion of it is normally used as floor fill and plinth fill material but the residue is still in huge quantum, thus its use in the new concrete provides the solution to some extent. It is also evident that the search of alternative indigenous materials for conventional constituents of concrete is an energetic area of research amongst the researchers around the world. The use of demolishing waste thus meets this criterion also [1]-[2]. Therefore, the research on the use of this material in new concrete has been carried out around the world by several scholars since past few decades. Although the waste has been used as fractional or full replacement of different constituents of concrete but its use as coarse aggregates has been preferred as it occupies more space in concrete matrix thus used in more quantum. Despite the good number of attempts. It is evident from the literature that more research in the area is required due to scatter in the results of published research.

It is noticed that greater water absorption, lesser specific gravity and lower strength are the issues associated with the recycled aggregates from demolishing waste [2]. Various techniques have been suggested to improve the short comings of recycled aggregates. Among them, recycling techniques, treatment of the aggregates, use of admixtures, synthetic and natural additives, fibers etc. are few examples. Fibers in concrete act as reinforcement and improves the properties. It is therefore, proposed to conduct the research to evaluate the effect of nylon fibers on the compressive strength of concrete specimens made by using partial replacement of conventional coarse aggregates with coarse aggregates from demolishing waste.

2. Literature Review

The review of relevant state of art not only give the details of work done in the area but also provides guidelines for future work. Therefore, this section summarizes the available relevant work done by different scholars regarding the topic.

Various scholars of research community around the world have designed different project and conducted research using recycled aggregates from demolishing waste to study the properties of the aggregates, properties of concrete at fresh and hardened state. General observation of the scholars is that the properties of recycled aggregates deviates than the properties of conventional aggregates mainly due to age of concrete, mortar adhered with the aggregates, service conditions of the parent infrastructure, etc. [2]. The deviation in properties of aggregates result in decrease in the strength properties of the hardened concrete. On the other hand, compressive strength of concrete is the significant property to ensure the durability and serviceability of concrete during its service life. Therefore, attempts have been made to improve the compressive strength of RAC. To this end Memon et. al. [3] used marble dust to check the improvement. Using various dosages of the material authors observed 5% dosage of marble dust is optimum for better strength of the product. Not only the marble dust but fly ash has also been attempted [4] as cement replacement additive for improvement of compressive strength of RAC. In this research article authors used different cement replacement levels with fly ash to check the effect on compressive strength. From the test results 7.5% replacement level was recommended as optimum for improved compressive strength. In another attempt Nasruddin et. al. [5] in their laboratory investigations used 30% candlenut shell to reinforce the recycled aggregate concrete. The authors used non-destructive testing to estimate the compressive strength of 28-day cured (wet and dry curing) concrete samples. The authors observed enhancement in the compressive strength from 23 – 27 MPa and concluded that the use of candlenut shell up to 30% has good potential to improve the compressive strength of recycled aggregate concrete even higher than that of conventional concrete.

Hamoodi et. al. [6] in their research used corbels to study their effect on the shear strength of recycled aggregate concrete. The authors used eight specimens to test the parameters. The comparison of results with ACI and EC2 provisions revealed authors that both provisions give conservative results in comparison to laboratory testing. The authors also observed that presence of the recycled aggregates not only lowered the strength but cracking load also. Based on the findings authors concluded 50% replacement by recycled aggregates as optimum. The authors further argued that reduction in a/d ratio leads to improved failure and cracking load. On the other hand, Bheel et. al. [7] millet husk ash to study its effect on compressive strength. The research used 180 concrete specimens with target strength of 25 MPa by replacing cement in the dosage of 5%, 10%, 15% and 20%. At the curing age of 90 days authors observed improvement in compressive, tensile, and flexural strength than target strength. Wang et. al. [8] on other hand used nano silica modified recycled aggregates in development of concrete. The compression of the results with conventional concrete revealed good improvement in various properties of proposed concrete.

The use of fibers to enhance various properties of conventional concrete have been studied well [9] - [13]. Literature is evident for various attempts of improving the properties of recycled aggregate concrete using fibers. Lei et. al. [14] used polypropylene and glass fiber to study the mechanical properties of the concrete. The research utilized different lengths and mass ratio of fibers to develop 28-day cured samples. These samples were then exposed to salt solution and freeze-thaw action followed by checking the compressive strength. The test results showed decrease in compressive strength for samples exposed to salt solution. Whereas improvement in the parameter due to addition of fibers was also evident from the test results. The strength improvement of recycled aggregate concrete has also been attempted by Tang et. al. [15] using binary blending of nano-silica and silica fume. The authors argued that the silica fume improves the concrete strength at later age where as pozzolanic characteristics of nano-silica help in gaining better strength at early age. Therefore, the combined use of the materials will help in improving the strength. The same was observed from strength test results and XRD analysis of the samples. Based on the obtained outcomes writers concluded optimum amount of silica fume equal to 6% and nano-silica equal to 2 or 3%.

Alabi and Arum [16] in their research program used lathe waste steel fiber to find the mechanical properties of recycled aggregate concrete. The authors used five batches of specimens with (0%, 25%, 50%, 75% and 100%) replacement of conventional coarse aggregates with coarse aggregates from demolishing waste. A mix (1:2:4), 0.45 water cement-ratio and 1.25% constant dosage of fibers were used to cast the specimens. The observations of workability, compressive and tensile strength results showed the authors adverse effects. However, the authors observed that the practice of the waste materials in desired area may reduce global greenhouse impact. The similar observations were made by Rao and Sastri [17] while using polypropylene fiber in development of high strength recycled aggregate concrete.

Lee [18] studied the permeability and mechanical properties of recycled aggregate concrete using 100% recycled aggregates and nylon fibers in the dosage of 0.6 and 1.2 kg/m^3. The conventional and SEM testing of the samples showed the authors lower performance of the concrete attributed to the old mortar adhered with the recycled aggregates. Based on the results authors argued that 1.2 kg/m^3 dosage of the fiber yield better results in comparison to conventional concrete. Not only the above-mentioned fibers, but carbon fibers have also been tried by Zaid et. al. [19]. The researchers replaced 35%, 70% and 100% dosage of recycled aggregates and 2%, 4% and 6% carbon fibers in development of the concrete specimens. The test results of 90 specimens for compressive, tensile, and flexural strength showed the authors improvement for all parameters of the study in addition to increased energy absorption capacity of the concrete. Analogous to it Ismail and Ramli [20] also observed improved energy absorption and impact resistance of the concrete when treated RCA was used in development of recycled aggregate concrete. Basalt fiber is another type of fibers from waste material. It has been used by Fang et. al. [21] to study the compressive, tensile strength, modulus of elasticity and failure modes of concrete. The research employed 0.2% dosage of the fiber in development of the concrete samples. Using test results the authors developed numerical expression for the strength of the concrete. Cross verification of the same showed good agreement of the developed formula with test results.

Compressive strength of recycled aggregate concrete has also been studied for various other aspects, i.e., effect of aggregate size [22], effect of curing methods [23], effect of height to diameter ratio of cylinders [24], gap grading [25], higher water cement ratio [26]. Several other factors have also been studied for concrete made with recycled aggregates from demolishing waste, i.e., relationship between cubical and cylindrical strength of RAC [27], Regression analysis for modelling fire effect of reinforced RAC beams [28], flexural behavior of reinforced RAC beams under long-term loading [29], Effect of 12-hour [30] and 18 hours [31] fire on flexural behavior of reinforced RAC beams, influence of mould dimension (size) on compressive-strength of green concrete specimens (cubes) [32], shrinkage of RAC panels [33], permeability and water penetration of recycled aggregate concrete [34], quality of RAC beams using UPV method [35], trend line analysis of weight vs compressive strength of RAC [36], weight versus tensile strength of concrete cylinders [37].

The above discussion of available state of art relevant to the subject of proposed investigation shows that good quantum of work has been done on the use of the recycled aggregates in development of green concrete. Various additives including different types of fibers have also been tested for improvement of various properties of the concrete. The literature is either silent or very less work is reported on use of the nylon fiber for improvement of compressive strength. Also, the scatter in the results shows more work is needed in the field to reach a certain level of confidence on use of the materials. Consequently, this study work proposed the practice of both locally available demolishing waste and nylon fibers in development of concrete to check the effect of nylon fibers on compressive strength of recycled aggregate concrete. It will not only lower the burden of the waste management to some extent but also help in developing the method for improving the compressive strength of RAC.

3. Material and Testing

This section provides the details of the materials used and tests performed for the evaluation of workability and strength of recycled fibrous concrete.

3.1 *Conventional Ingredients of Concrete*

For conventional ingredients of concrete, ordinary Portland cement under brand name lucky cement was used. The fineness of cement was checked with #100 sieve and was found equal to 97.1%. Initial and final setting time of cement were recorded equal to 62 min and 372 min respectively. Whereas the consistency of cement was found equal to 32%. The observed parameters of cement agreed well with ASTM C150 [38] standards.

Hill sand was used as fine aggregates. The sieve analysis of hill sand revealed its fineness modulus equal to 2.73. The value obtained falls in the range of medium sand and agrees well with ASTM C136 provisions [39]. The sieve analysis results of fine aggregates are listed in Table 1. Conventional aggregates were obtained from approved sources of the aggregates with maximum size equal to 25 mm. The sieve analysis of the aggregates revealed fineness modulus of the material equal to 5.67. The conventional aggregates of concrete are shown in Fig. 1. The sieve analysis results of coarse aggregates are listed in Table 2. Potable water with pH value equal to 6.9 was used for mixing of the ingredients of concrete.

Table 1

Sieve analysis of fine aggregates

Sieve Size	Retained (g)	Retained (%)	Cumulative Retained (g)	Cumulative Retained (%)	Passing (%)	ASTM Range
#4	0	0	0	0	100	95 - 100
#8	161	16.1	16.1	16.1	83.9	80 - 100
#16	210	21	37.1	37.1	62.9	50 - 85
#30	98	9.8	46.9	46.9	53.1	25 - 60
#50	303	30.3	77.2	77.2	22.8	5 - 30
#100	182	18.2	95.4	95.4	4.6	0 - 10
#200	35	3.5	98.9	98.9	1.1	0 - 3
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Table 2

Sieve analysis of coarse aggregates

Sieve#	Passing (%) Conventional Coarse Aggregates	Passing (%) Recycled Coarse Aggregates	ASTM Range Range
1”	100	100	95 – 100
3/4”	80.4	82.72	40 – 85
1/2”	51.4	57.72	25 – 60
3/8”	11.72	14.72	0 – 15
#4	2.88	0.64	2 – 10
#8	0.4	0.24	0 – 5

3.2 *Recycled Aggregates*

To develop recycled aggregates, demolishing waste was obtained from vicinity of Nawabshah city. Large blocks of the waste were reduced to recycled aggregates of maximum 25 mm size by hammering. Fig. 2. shows the pictorial view of the waste and recycled aggregates. The obtained material was sorted for impurities, then washed and dried at room temperature. Similar to conventional coarse aggregates, recycled aggregates were also sieved. The fineness modulus was recorded equal to 5.55. The sieve analysis results of the aggregates are given in

Table 2. The recycled aggregates were used in equal proportion with conventional aggregates (50%) following the recommendations of Oad and Memon [40]. The basic properties; water absorption, specific gravity, unit weight, density, abrasion, and soundness; of both recycled and conventional aggregates were determined following the standard procedure of the tests. The obtained results are listed in Table 3.

Fig. 1. Conventional Ingredients

Fig. 2. Demolished Waste and Recycled Aggregates

Table 3

Basic properties of coarse aggregates

Property	NCA	RCA
Water absorption (%)	1.72	3.65
Specific gravity	2.54	2.38
Unit weight (kg/m^3)	2186.2	1985.4
Density (kg/m^3)	2472.6	2361.8
Abrasion (%)	16.4	29.6
Soundness (%)	4.52	6.81

3.3 Nylon Fibers

The nylon fibers used in this study were cut from nylon wire obtained from market. The dosage of fibers was used equal to 0%, 0.25%. 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75% and 2% by weight of cement. The mix with 0% fibers was control mix and used to compare the results of proposed concrete. Additionally, one mix with equal proportion of conventional and recycled aggregates but no fibers was prepared to check and compare the effect of nylon fibers. The details of the batches are given in Table 4. The pictorial view of the fibers is shown in Fig. 3. The length of fibers for all dosages was used equal to 25 mm.

Fig. 3. Nylon Fibers

(a)

(b)

Fig. 4. Cube Specimens (a) and Cylinders Samples (b)

3.4 Slump cone test

Using above defined ingredients total of ten concrete mixes were designed. For all mixes 1:2:4 mix ratio with 0.5 water cement ratio were used. All the ingredients were measured by weight. For each mix the required ingredients were thoroughly mixed then water was added, and mixer was run till uniform paste was formed. Slump cone test for each mix was performed to check the workability of the concrete in accordance with ASTM C143 [41]. Obtained slump values for all mixes is listed in the last column of Table 4.

Table 4

Concrete ingredients and slump value

Batch	NCA (%)	RCA (%)	Nylon Fiber (g)	Cement (Kg)	Sand (kg)	NCA (kg)	RCA (kg)	Water (kg)	Slump (mm)
CM	100	0	0	6.42	12.9	25.7	0	3.29	81
RAC	50	50	0	6.42	12.9	12.9	12.9	3.29	73
B1	50	50	16.1	6.42	12.9	12.9	12.9	3.29	70
B2	50	50	32.1	6.42	12.9	12.9	12.9	3.29	66
B3	50	50	45.2	6.42	12.9	12.9	12.9	3.29	62
B4	50	50	64.2	6.42	12.9	12.9	12.9	3.29	59
B5	50	50	80.3	6.42	12.9	12.9	12.9	3.29	53
B6	50	50	96.3	6.42	12.9	12.9	12.9	3.29	48
B7	50	50	112	6.42	12.9	12.9	12.9	3.29	42
B8	50	50	128	6.42	12.9	12.9	12.9	3.29	31

3.5 Compressive Strength

For compressive strength evaluation five standard size (6"x6"x6") cubes were cast in each mix. The casting of the specimens was done in standard fashion. For compaction table vibrator was used till the cement slurry covered the top surface. After 24-hours all the specimens were allowed for curing by fully immersing in potable water for 28-days. After the end of required curing time, specimens were taken out of water and allowed to air dry for 24-hours Fig. 4 (A). All the specimens in turn were crushed in universal testing machine under gradually increasing load. Crushing load was recorded (Table 5) and converted into compressive strength using standard formula (P/A). Fig. 5 shows few specimens during testing.

Fig. 5. Testing For Compressive Strength

Table 5

Peak load of concrete specimens for compressive strength

Batch NO	Nylon Fiber (%)	RCA (%)	Load (kN)					Average Load (kN)
			1	2	3	4	5	
CM	0	0	526.5	567.0	549.0	537.8	560.3	548.1
RAC	0	50	418.5	429.8	417.0	436.5	465.7	433.5
B 1	0.25	50	541.5	509.5	552.4	535.7	502.8	528.4
B 2	0.5	50	560.4	545.8	561.3	562.3	585.7	563.1
B 3	0.75	50	590.5	584.8	576.5	592.8	589.9	586.9
B 4	1	50	649.5	650.5	613.0	628.8	632.8	634.9
B 5	1.25	50	629.0	633.5	641.0	658.0	647.3	641.8
B 6	1.5	50	676.3	692.7	681.5	673.0	669.8	678.6
B 7	1.75	50	613.0	629.0	618.5	607.8	608.0	615.3
B 8	2	50	601.5	578.1	606.5	592.3	617.2	599.1

3.6 Tensile Strength

To evaluate the tensile strength of proposed concrete standard sized cylinders (6"/12") were prepared in similar manner as the specimens for compressive strength were prepared. Fig. 4 (B) shows few of the specimens. After the elapse of curing age (28-days) each specimen was tested (Fig. 6) in turn in universal testing machine under gradually increasing load. The peak load was recorded and is listed in Table 6. The split tensile strength was then computed from the recorded load using standard formula (2P/πLD).

Fig. 6. Testing For Tensile Strength

Table 6

Peak load of concrete specimens for tensile strength

Batch: No.	Nylon Fiber (%)	RCA (%)	Load (kN)					Ave: Load (kN)
			1	2	3	4	5	
CM	0	0	202	231	206	204.7	216.7	212.1
RAC	0	50	158	163	163	171.3	176.6	166.5
B 1	0.25	50	207	202	208	201.4	192.7	202.1
B 2	0.5	50	213	211	215	216.1	221.5	215.2
B 3	0.75	50	238	232	224	241.3	240.6	235.1
B 4	1	50	249	245	236	238.7	245.9	242.8
B 5	1.25	50	238	245	241	251.9	244.6	244.2
B 6	1.5	50	261	264	256	258.7	253.0	258.5
B 7	1.75	50	266	273	265	278.9	272.7	271.0
B 8	2	50	279	281	283	284.2	282.0	281.9

4. Results and Discussion

The comparison of the results of basic properties of recycled aggregates with conventional aggregates revealed that water absorption of recycled aggregates was 212% of the water absorption of conventional aggregates. The specific gravity of the aggregates was observed 6.3% less than that of conventional aggregates. Similarly, unit weight, density, abrasion and soundness of recycled aggregates was recorded -9.2%, -4.5%, +162%, and +150.6 of the conventional aggregates. The deviation of the properties of recycled aggregates confirms the finding reported in literature and are mainly due to the age, old mortar attached with aggregates and exposure of the old concrete during its service life.

The sieve analysis results of fine and coarse aggregates along with ASTM minimum and maximum values at various sieves are plotted in Fig. 7 and Fig. 8. From these Fig.s it may be observed that the percentage passing of the aggregates on various sieves confirms the allowable range of relevant ASTM standard. It ensures that the well graded aggregates have been used in the concrete mix.

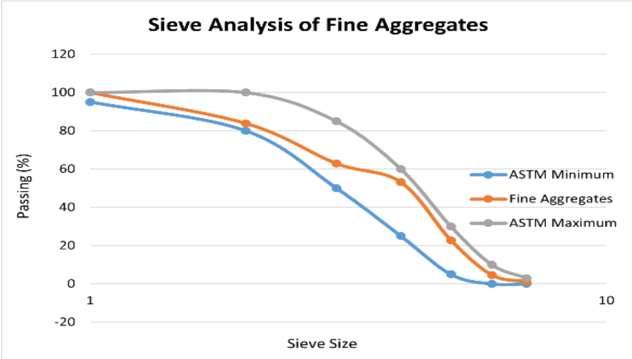

Fig.7. Sieve Analysis of Fine Aggregates

Slump values reported earlier are plotted as bar graph in Fig. 9 for comparison. It may be observed that due to addition of recycled aggregates slump reduced (9.87%). The reduction in slump was further aggravated due to introduction of nylon fiber in the recycled aggregate concrete (13.65 – 61.7%). Increase in the dosage of nylon fibers decreased slump further. This should be considered in mix design to maintain the workability by increasing the water cement ratio or by using plasticizer. Comparing the results of slump at 1.5% dosage of nylon fibers, it is observed that value of slump obtained in present study is 41% better than the value obtained by Bheel et. al. [43] at similar dosage of nylon fibers.

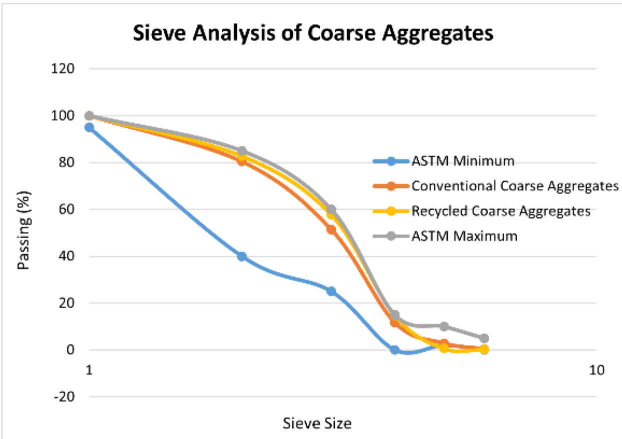

Fig. 8. Sieve Analysis of Coarse Aggregates

Slump values reported earlier are plotted as bar graph in Fig. 9 for comparison. It may be observed that due to addition of recycled aggregates slump reduced (9.87%). The reduction in slump was further aggravated due to introduction of nylon fibers in the recycled aggregate concrete (13.65 – 61.7%). Increase in the dosage of nylon fibers decreased slump further. This should be considered in mix design to maintain the workability by increasing the water cement ratio or by using plasticizer. Comparing the results of slump at 1.5% dosage of nylon fibers, it is observed that value of slump obtained in present study is 41% better than the value obtained by Bheel et. al. [43] at similar dosage of nylon fibers.

The compressive strength of each specimen of all batches was computed using standard formula. The obtained results are tabulated in Table 7. It was observed that the obtained values were within 15% deviation with mean values. The average compressive strength of five samples in each batch was evaluated and is shown in Fig. 10. It may be observed from the Fig. that the addition of recycled aggregates reduced the compressive strength by 21%. This loss was approximately compensated with introduction of 0.25% nylon fibers in the recycled aggregate concrete. The increase in compressive strength continued with increase in nylon fiber contents with maximum (23.82%) up to 1.5%, then the strength reduced but was more than the compressive strength of conventional concrete. Considering the maximum value obtained in this work the optimum dosage of nylon fibers is observed 1.5%. The percentile deviation of average compressive strength of nylon fiber reinforced concrete with conventional and recycled aggregate concrete is shown in Fig. 11. The better interlocking of the ingredients of concrete due to presence of nylon fibers may be observed from Fig. 12. It shows that complete rupture of the cubes was prevented due to bonding of the nylon fibers. Further comparison of compressive strength (30.16 MPa) results showed that the results obtained in this work (at optimum dosage) were better than the results published by Nasruddin and Mushar (27 MPa) using candlenut shell [5]. The results were also observed better compared to the results published by Oad and Memon (17.6 MPa) [40] using only recycled aggregates. Compressive strength obtained in this research work was also observed 15.12%, 12.4%, and 13.52% better than those obtained by Ahmed et. al. [42], Bheel et. al. [43], and Murtaza et. al. [44] respectively. This shows the good impact of nylon fibers on the compressive strength of recycled aggregate concrete.

Table 7

Compressive strength of concrete specimens

Batch No.	Nylon Fiber (%)	RCA (%)	Compressive Strength (MPa)					Ave: CS (MPa)
			1	2	3	4	5	
CM	0	0	23.4	25.2	24.4	23.9	24.9	24.4
RAC	0	50	18.6	19.1	18.5	19.4	20.7	19.3
B 1	0.25	50	24.1	22.6	24.6	23.8	22.3	23.5
B 2	0.5	50	24.9	24.3	25.0	25.0	26.0	25.0
B 3	0.75	50	26.2	26.0	25.6	26.3	26.2	26.1
B 4	1	50	28.9	28.9	27.2	27.9	28.1	28.2
B 5	1.25	50	28.0	28.2	28.5	29.2	28.8	28.5
B 6	1.5	50	30.1	30.8	30.3	29.9	29.8	30.2
B 7	1.75	50	27.2	28.0	27.5	27.0	27.0	27.3
B 8	2	50	26.7	25.7	27.0	26.3	27.4	26.6

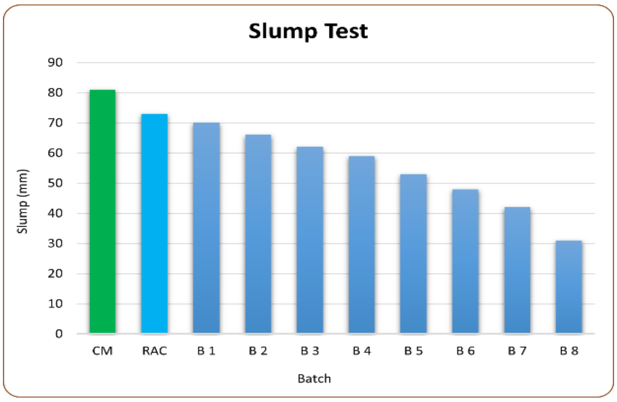

Fig. 9. Slump Values

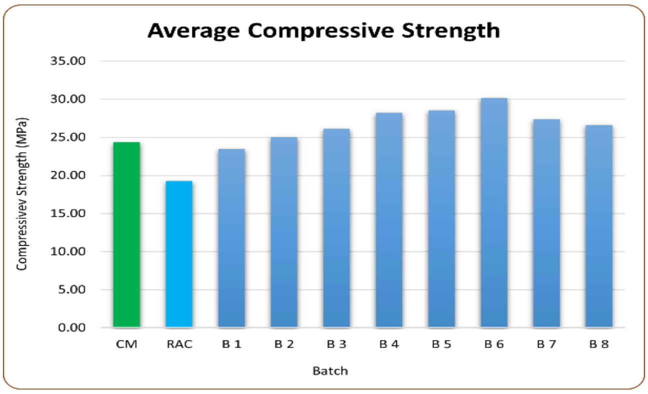

Fig. 10. Average Compressive Strength

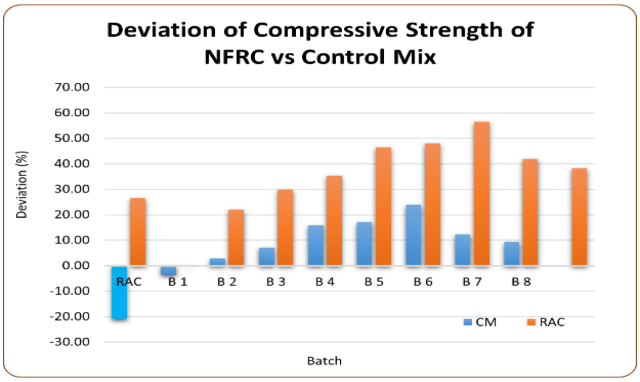

Fig.11. Deviation of Compressive Strength

Fig. 12. Specimen After Crushing

The load recorded during split tensile strength testing of the cylindrical specimens were then used to compute the tensile strength. Obtained results are listed in Table 8. The average tensile strength of five samples in each batch is plotted in Fig. 13. Similar to compressive strength, addition of recycled aggregates in concrete reduced the tensile strength by 21.5%. But addition of lowest dose of nylon fibers (0.25%) reverted the loss to much extent. Thereafter the tensile strength increased with increase in the nylon fiber content. At the optimum dosage of nylon fibers for compressive strength, the tensile strength was recorded about 22% higher than that of conventional concrete and 55% higher than recycled aggregate concrete without nylon fibers. Unlike compressive strength the tensile strength kept on increasing with increase in nylon fiber contents up to the maximum dosage used in this research work. The percentile difference of tensile strength of proposed concrete vs control mix is shown in Fig. 14. The comparison of tensile strength (3.66 MPa) results obtained in this work with (at optimum dosage) were observed better than those published by Hanif et. al. (2.3 MPa) [10] using nylon fibers and recycled aggregates. The tensile strength results of present work were also observed 12.4%, 10.7%, and 9.3% better than those obtained by Ahmed et. al. [42], Bheel et. al. [43], and Murtaza et. al. [44] respectively.

Table 8

Tensile strength of concrete specimens

Batch	Nylon Fiber (%)	RCA (%)	Tensile Strength (MPa)					Ave: TS (MPa)
			1	2	3	4	5	
CM	0	0	2.85	3.28	2.91	2.9	3.07	3
RAC	0	50	2.24	2.3	2.31	2.42	2.5	2.36
B 1	0.25	50	2.92	2.85	2.94	2.85	2.73	2.86
B 2	0.5	50	3.01	2.98	3.05	3.06	3.13	3.05
B 3	0.75	50	3.36	3.28	3.18	3.41	3.41	3.33
B 4	1	50	3.52	3.46	3.34	3.38	3.48	3.44
B 5	1.25	50	3.37	3.46	3.42	3.57	3.46	3.46
B 6	1.5	50	3.7	3.73	3.62	3.66	3.58	3.66
B 7	1.75	50	3.76	3.86	3.75	3.95	3.86	3.84
B 8	2	50	3.95	3.98	4.01	4.02	3.99	3.99

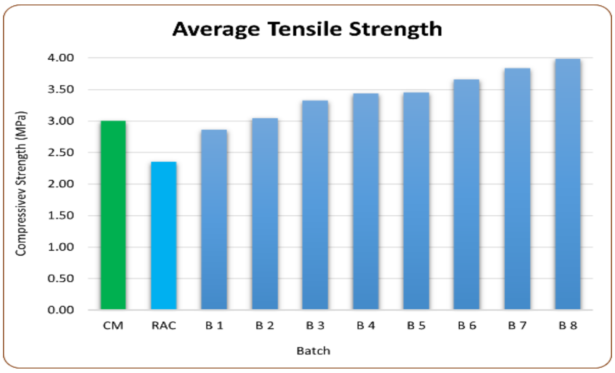

Fig. 13. Average Tensile Strength

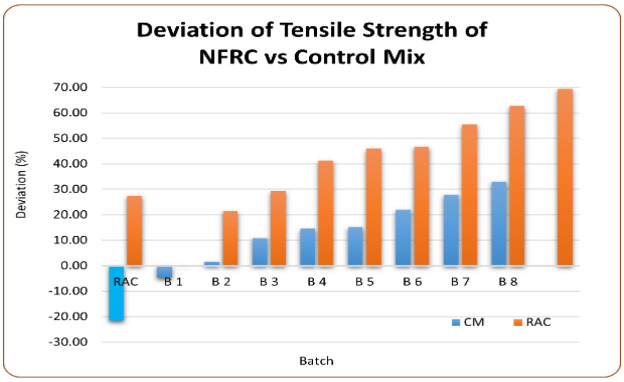

Fig. 14. Deviation of Tensile Strength

The above discussion of the results and comparison with those reported in literature clearly shows the positive impact of the recycled aggregates and nylon fibers on the enhancement of the strength properties of recycled aggregates. Further improvement is also anticipated using fine increment of the fibers on strength properties. Also, the use of the recycled aggregates developed at mass scale will lead to economy of the concrete matrix.

5. Conclusion

In this research study laboratory investigation on effect of recycled aggregates and nylon fibers in concrete are presented. Based on the outcome of the study following are concluded.

1. Recycled aggregates and nylon fibers adversely affects the workability of concrete. Increased contents of fibers aggravate the slump reduction.
2. Loss of compressive strength due to recycled aggregates can be compensated by using nylon fibers even at lower dosage. At the lowest dose of nylon fibers (0.25%) the loss of compressive strength of fiber reinforced recycled aggregate concrete was just 3.6%. Increase in fiber content increased the compressive strength up to 1.5% of the fibers. Beyond 1.5% dose of the fibers compressive strength reduced but was higher than both conventional and recycled aggregate concrete. At optimum dosage compressive strength was observed 23.82% and 56.55% more than the compressive strength of conventional and recycled aggregate concrete.
3. At the optimum dosage tensile strength was observed 21.91% and 55.31% higher than the tensile strength of conventional and recycled aggregate concrete. Tensile strength increased further with increase in the percentage of nylon fibers and is anticipated that if nylon fibers are increased beyond the maximum dose used in this work, the tensile strength will increase further. The tensile strength results show positive impact of nylon fibers on tensile strength tending the concrete towards ductile than brittle.

It is further observed that better interlocking of concrete ingredients is achieved due to presence of nylon fibers in the concrete matrix. 1.5% of nylon fibers and 50% recycled coarse aggregates from demolished concrete waste are suitable for achieving better compressive and tensile strengths.

6. No conflict

The authors declare no conflict of any interest at any stage of this research work.

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