Flexural Strength and Modulus of Elasticity of Concrete Beam Cast with Binary Blending of Recycled Concrete Aggregate and Marble Dust

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Abstract

This research paper presents the combined effect of recycled coarse aggregates and marble dust on the flexural strength and modulus of elasticity of concrete. Use of the waste materials in concrete leads to sustainable development; and is the need of the day. Recycled aggregates were processed from demolishing waste and ensured by sieve analysis for well-graded concrete. Marble dust was used as cement replacement from 2.5% to 10% in increments of 2.5%. Recycled aggregates were used in equal dosage with conventional aggregates. A total of five batches of beams and cubes were cast using normal mix concrete. The curing of the specimens was done for 28 days. Ultrasonic pulse velocity testing was done to evaluate the modulus of elasticity. The same was also evaluated using an empirical equation of ACI and from the literature. A comparison of the results shows that both UPV testing and numerical equation by ACI can comfortably be used for evaluation of the modulus of elasticity of recycled aggregate concrete. Beams were tested under central point load for flexure. Comparison of flexural strength and deflection with control concrete shows that a 5% dosage of marble dust as cement replacement along with 50% replacement of conventional coarse aggregates with coarse aggregates from demolishing waste is optimum as with this replacement level residual flexural strength is 88% and the deflection is only 5% more than control concrete and less compared to the maximum approximate deflection allowed by ACI-318.

Keywords—Demolishing waste, recycled aggregates, green concrete, workability, flexural strength, marble dust, cement replacement

1 Introduction

From caves to skyscrapers and from mud and stone to concrete and steel humans have witnessed drastic changes in material and methods and architecture and size of structures. This whole development although has taken centuries now has created the problem of congestion in the city centers of the world. On the other hand, the growing population, and migration of people from less developed areas to city centers continued. It demands more and more residential and associated facilities. This forces the industry to opt for vertical expansion of the structures. Several issues related to resources, environments, general surroundings, waste, and its management are associated with this mass development around the globe. Therefore, both academia and industry are focusing on sustainable development instead of conventional. To this end idea of using waste materials as a replacement for one or other ingredients of conventional concrete has popularity and has been an active area of research for a couple of decades. The major portion of the concrete body is coarse aggregates. Therefore, literature reports a good many attempts on the use of demolishing waste as coarse aggregate in new concrete [1]. The technique releases the burden on landfills to some extent. Even saves the agricultural lands as due to unavailability of space the waste is dumped in or near by such lands resulting in disturbance and deterioration of the valuable land like in Pakistan. Even to some extent, the technique lessens the above-mentioned issues associated with mega-development.

The mega development also requires beautification and is accomplished by using various non-structural elements. Marble is one such product and is extensively used due to its look and durability. The product is obtained by quarrying the relevant rocks and

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processing them in the desired shape and size. The process generates waste in huge quantums and adds up the waste management problem. This waste can be converted into powder for cement replacement, fine granular material for sand replacement, and coarse particles for coarse aggregate replacement [19]. In all three forms marble waste is used in conventional concrete to study its effect on fresh and hardened properties. The next section of this research paper provides the literature review where it may be observed that the combined use of both materials is either least or absent, particularly with reference to flexural strength or flexural behavior. Therefore, the research presented in this article aims on experimental investigation of the effect of binary blending of demolishing waste and marble waste in place of coarse aggregates and cement on flexural behavior of the concrete.

2 Literature Review

The use of demolishing waste in infrastructure development is not new. Earlier it was used in floor, plinth protection, and other filling areas. Even then the residual quantum of the waste requires proper management. Its use as a replacement for concrete ingredients is questionable due to the age and strength of the source concrete, the mortar attached to it, the processing of waste into aggregates, etc. These issues have been addressed by the scholars. The review [1][2] of the work done in the field highlights the issue, their impact, and remedies. Also, it is pointed out that proper implementation of the rules and regulations by the concerned governments will help in streamlining the use of the material. It is also reported that soaking aggregates [3] from demolishing waste into acetic acid followed by rubbing results in lesser water absorption of the aggregates and increased strength of the concrete using it.

The waste from laboratory-tested cylinders has also been attempted in preparation for new concrete beams to check their flexural strength [4]. The research reports the minimum difference in peak load than their counterpart made from all conventional aggregates irrespective of the dosage of the recycled aggregates. Another similar attempt by Sato et al. [5] reports that demolishing waste can be used as coarse aggregates with minimum loss of flexural capacity if proper design and proper limit of application are considered. Yang et al. [6] also used demolishing waste as coarse aggregates in the dosage of 30%, 50%, and 100% to check the flexural capacity. By varying the tensile reinforcement ratio equal to 0.5%, 0.79%, and 1.14% the authors observed similar crack patterns but lesser flexural strength in the beams. Also, they observed that the ductility of the beams was not influenced due to the dosage of the recycled aggregates. Hence it may be said that the recycled aggregates in new concrete do not influence the ductility of the concrete.

It is apparent that the introduction of recycled aggregates in the concrete affects the flexural strength. Varying dosages have been tried by scholars with different water-cement ratios, and different and fixed steel percentages. At 50% replacement level, Memon and Bhatti [7] observed 88% residual strength of RC beams, Oad et al. [8] reports 8.8% loss of flexural strength for 7-day cured normal mix RC beams, 5.5% loss of the strength for 28-day cured normal mix RC beams, and 11.68% loss of the strength for 28-day cure rich mix concrete beams [9]. The effect of fire on the flexural capacity of reinforced concrete beams is one of the hazards that sometimes is to be faced by the structures. Fire not only destroys the appearance of the structures but also deteriorates their resisting capacity. To this Buller et. al. studied the effect of 1000°C fire on reinforced recycled aggregate beams. They observed about 8% reduction in bearing capacity when exposed to fire for 6 hours [10], 22% reduction when exposed to fire for 18 hours [11], and 32.41% when exposed to fire for 24 hours [12]. Demolishing waste has also been used to study the long-term effect of loads on beams [13], and the bending behavior of concrete-filled filled FRP-tubes [14] among many other effects.

Marble waste has also been used in conventional concrete as a replacement for all three ingredients of concrete in turn. Marble dust from this waste is generally used as a replacement for cement. In an attempt, to find the optimized dose of marble dust in concrete Kumar and Kumar [16] used the dust up to 20% in increments of 5% with a water-cement ratio equal to 0.43. From the laboratory investigations, the authors found a 10% dose of marble dust as optimum for compressive strength and 15% for tensile strength. Gurumoorthy [17] concluded his research finding with 25% as the optimum dosage of marble dust as cement replacement for compressive, tensile and flexural strength. Another study by Ashish et. al. [18] reports 15% as optimum dose of marble dust for compressive strength and 10% for tensile and flexural strength. Literature also reports 7.5% [20] marble dust as optimum for M35 concrete and 17.5% [21] for M20 concrete. Khaliq et al. [25] on the other hand report 10% as the optimum dosage without any substantial loss of strength.

Marble waste as sand replacement is also used to study compressive and tensile strength by Ofuyatan et. al. [15] The authors prepared specimens with 15%, 25% and 35% dosage of marble dust and 0.5 water-cement and cured them up to 56 days. The laboratory investigation showed the authors that at 25% dosage of marble dust as sand replacement compressive strength increased by 11% and tensile strength by 25%. From this study, it may be observed that the sand replacement by marble waste give better results but other studies on the topic show a different set of results. Laboratory investigations to check the effect of marble dust on conventional, self-compacting and polymer mix concrete showed Ulubeyli and Artir [22] that only properties of conventional concrete improved. Marble waste along with granite waste in equal proportion has been attempted by Lal and Kumar [23] as coarse aggregates in concrete. They found an increase in compressive strength up to 30% dosage beyond which the strength decreased. Marble dust has also been attempted in air-cooled mortars by Seghir et al. [24] In this study authors found that the compressive strength of mortar decreases due to the induction of marble dust but permeability increases.

The modulus of elasticity of concrete containing different types of coarse aggregates and mineral additives has been addressed by different scholars using experimental procedures and empirical equations. To this end, Park et al. [32] coined out empirical equation arguing that existing equations in literature are not applicable to the whole data of recycled aggregates. Therefore, the authors used 1300 existing data sets to develop the numerical equation for modulus of elasticity, considering the type of aggregates and the ratio of mix. Numerical prediction of modulus of elasticity using the M5' model tree algorithm over 450 data sets from literature was also done by Behnood et al. [33]. The use of the algorithm was simple with respect to use and convenient with respect to other existing models. The cross-verification of the model showed 80% efficiency of the model. Dilbas et. al. [34] in their experimental program studied the modulus of elasticity and energy capacities of concrete containing recycled aggregates and fly ash. The authors compared numerical equations proposed by six standards. Based on their observations authors observed that most of the standards underestimate the values of the parameters. Therefore, the authors proposed their own equation in agreement with experimental results using 5% fly ash and 30% recycled aggregates as optimum values of the additives. Kazmierczak et al. [35] studied the effect of water absorption of recycled aggregates on the dynamic modulus of elasticity. Based on their work they argued that the existing equation proposed by codes and developed in literature either does not consider the effect of water absorption or disagrees with the use of recycled aggregates, where on the other hand use of the recycled aggregates in concrete is highly demanding, therefore, it should properly be addressed. The authors also concluded that the equations proposed by the codes should be improved. The parameter has also been addressed by Chen et al. [38] in their experimental program. The authors used 1383 data sets from 154 publications to develop numerical equations for the modulus of elasticity using compressive strength, the replacement rate of conventional aggregates, and the quality of recycled aggregates. Using statistical analysis, the authors developed a reduction coefficient to be used with the numerical equation for the modulus of elasticity of concrete with conventional aggregates for predicting the modulus of elasticity of recycled aggregate concrete. In another research study, Reyes-Sanchez et al. [39] used 147 data sets from literature to develop a numerical equation for E of recycled aggregate concrete but considered absorption percentage, abrasion resistance, and dosage of recycled aggregates. Based on the obtained results authors concluded that the use of more independent variables yields a better equation for the purpose.

The flexural strength of concrete with steel waste and marble dust was studied by Gulmez [36] arguing that the product will not only be ecofriendly but also reduce the cost. From the study, the author observed that the introduction of steel chips reduced the workability, but substantial improvement was recorded due to the addition of the marble dust. However, water absorption was recorded to increase due to the addition of the waste material in concrete. The author recorded maximum flexural strength at 2% and 10% dosages of steel chips and marble dust respectively. Elansary et al. [37] in their experimental program studied flexural strength along with the mechanical behavior of concrete containing recycled aggregate by replacing 30%, 50%, and 100% conventional aggregates in 72 specimens cured for 7- and 28 days. The test results revealed that 100% replacement adversely affects all the properties of concrete including flexural strength. Whereas 30% and 50% replacement levels with careful consideration of water cement ratio yield good results of flexural strength. Marble waste has also been used as a replacement of fine and coarse aggregates in concrete. To this end, Benjeddou and Mashaan [40] recommend the use of it as mentioned above with a positive impact on the properties of concrete. The authors recommended it after performing sieve analysis, atomic absorption, spectrometry, calcium carbonate content, sand equivalent, abrasion resistance, micro devil test, flakiness test, and physical and chemical properties evaluation. Ofuyatan et al. [41] used recycled aggregates and marble dust to prepare the self-compacting concrete. Evaluation of fresh properties (slump, T50cm, V-funnel, L-Box tests), hardened properties (compressive, tensile, and flexural strength), microstructure and carbonation analysis showed the authors that fresh properties of concrete with recycled aggregates are not as good as those of concrete with conventional aggregates, but the use of the marble dust makes them equally good. Also, the observations revealed that the hardened properties particularly the flexural strength of the product were better compared to conventional concrete. Zaid et al. [42] on the other hand observed a 46% improvement in the flexural strength of concrete with marble dust and wheat straw ash. Additionally, authors also observed 16% and 29% reduction in water absorption and sorptivity of the material. Microstructural analysis of the proposed concrete showed that the use of the waste material in concrete is good and economical.

Mechanical properties of concrete with recycled aggregates and marble dust have also been addressed by Shang et al. [43] using machine learning techniques. Root mean analysis and other statistical measures of 344 samples showed the effectiveness of the techniques. In another attempt, Ahmad et al. [44] used marble waste a fine and coarse aggregate replacement and found that 60% dosage is optimum for better results of flexural strength. In a separate study, Ahmad et. al. [45] also used marble dust in combination with coconut shell ash in concrete. For the results, authors concluded 20% marble waste and 2% coconut shell ash as the optimum dosage of the waste materials for better results of flexural strength of the concrete. Marble dust as cement replacement in grouting material has also been used by Wang et. al. [46] who found it very suitable and economical with the least loss of the strength of the product.

From the above discussion, it may be observed that both waste materials; demolishing waste and marble waste; are independently used in concrete. But the results show variations. Also, the combined use of both waste materials in concrete especially with reference to flexural strength is either absent or least addressed. This shows that there is room for more research on the topic to improve the confidence level in use of the materials.

3 Materials and Testing

To achieve the proposed targets of the research methodology shown in Figure 1 was adopted. Different ingredients used for the preparation of the samples are discussed as under:

3.1 Recycled Aggregates

To prepare the recycled aggregates demolished waste (Figure 2) was collected from the demolition of a single-story reinforced concrete house in the locality of Nawabshah City. The blocks of the waste were hammered down to a maximum of 25 mm size being the largest size of the recycled aggregate used in this work. Thereafter, the material was washed and sorted for unwanted substances like cracked particles, debris, etc. (Figure 3).

3.2 Marble dust

Marble dust generated during the cutting of the marble tiles was collected from the marble tiles shop in Nawabshah. The collected material was sieved on *#200* sieve to ensure its fineness and fitness to replace cement (Figure 4).

3.3 Conventional Ingredients

Other conventional ingredients of concrete i.e., ordinary Portland cement, coarse aggregates, and fine aggregates were purchased from the local market. Water used for the preparation of concrete was collected from the water supply scheme of the city having a pH value equal to 6.8.

The summary of the methodology of the research work is given in Figure 1. The conventional ingredients of concrete obtained from the local market as mentioned earlier consisted, of cement under the brand name Pak Land, and fine and coarse aggregates from the Nooriabad quarries. Water used in the mix was obtained from the main water supply line of the city water supply. The demolishing waste in the shape of large blocks was brought to the laboratory from the demolishing site. After processing the demolished waste in recycled aggregates, both conventional and recycled aggregates were sieved as per ASTM standards to ensure well-graded aggregates in the concrete mix. The conventional ingredients, recycled aggregates, and marble dust were then used to prepare specimens as the details given in the subsequent section.

3.4 Casting of cubes and beams

In preparation of the specimens recycled and conventional coarse aggregates are used in equal proportion following the recommendation of Oad and Memon [26].

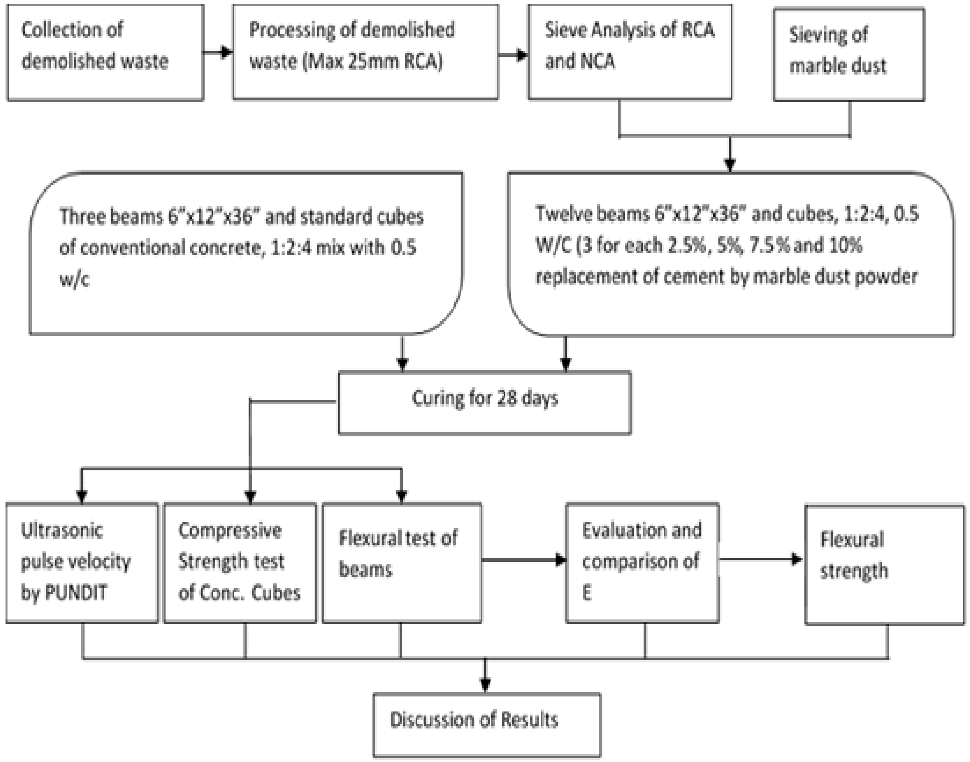

Fig. 1: Methodology of proposed research work

Fig. 2: Demolished waste

Fig. 4: Marble dust

Fig. 3: Recycled aggregates

Fig. 5: Cubes and beams

Cement replacement with marble dust powder is done in four levels i.e., 2.5%, 5%, 7.5%, and 10%. Therefore, four batches of the specimens with recycled material are prepared. Also, one batch of the specimens is prepared using all conventional ingredients. This batch is treated as a control and is used to compare the results of proposed concrete specimens. The details of the batches along with material quantities are given in Table 1. All the specimens are prepared using a 1:2:4 mix and designed water-cement ratio considering the use of waste material. Therefore, the difference in the quantity of water in the last column of Table 1 may be noted.

Both conventional and recycled coarse aggregates were sieved to ensure well-graded aggregates in the concrete mix. The fineness modulus of conventional coarse aggregates was recorded as equal to 4.58 whereas the same for recycled aggregates was obtained as equal to 4.55. Both results were in the range of the value specified by the concerned codes. In the preparation of specimens, weight batching, mixing by mixer, steel molds, and compaction by table vibrator was used. Standard size (6”x6”x6”) for cubes and 6”x12”x36” size for beams was adopted for all batches. After demolding, the specimens were allowed to air dry for 24-hour followed by curing for 28 days by fully immersing in potable water. Figure 5 shows a few samples.

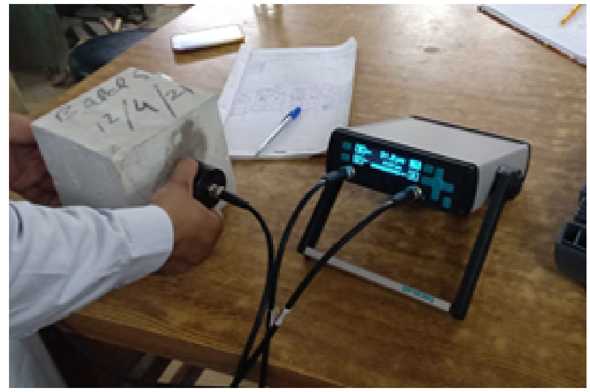

Fig. 6: UPV testing

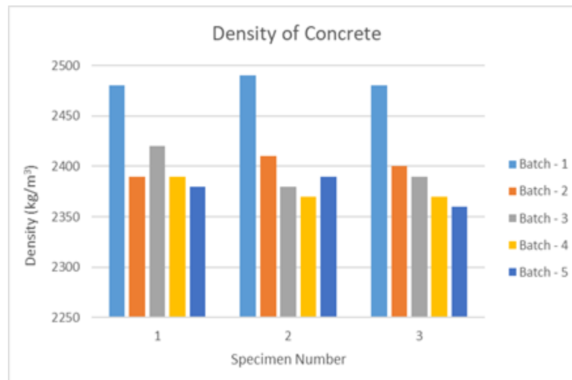

Fig. 7: Density vs Specimen Number

3.5 UPV testing

Ultrasonic pulse velocity testing is a type of non-destructive testing of concrete. This technique with the help of an instrument named PUNDIT was used in this research work to determine the time and velocity [27]. The velocity of both S-waves (V_S) and P-waves (V_P) was determined. Figure 6 shows the testing of a sample. Obtained readings are given in Table 2. Using the formulation given in the instruction manual of the instrument, the modulus of elasticity is evaluated using equation (1).

$$E = 2G(a + \upsilon) \tag{1}$$

Where G is the shear modulus and υ is the poisons ratio. Both parameters are computed under:

$$G = \rho V_S^2 \tag{2}$$

In the above expression, ρ is the density of concrete.

$$\epsilon = \frac{V_P^2 - 2V_S^2}{V_P^2 - V_S^2} \tag{3}$$

In the above expression density of concrete is required. Therefore, it is investigated for both conventional and recycled aggregate concrete in a standard fashion following the relevant ASTM provisions. The obtained results are shown in Figure 7.

3.6 Compressive strength

All the cubical specimens were tested for failure load in a universal testing machine under gradually increasing load (Figure 8). In turn, it was used to evaluate the compressive strength to be used for the computation of the modulus of elasticity. The experimental observations of the failure load and computed compressive strength are given in Table 3.

3.7 Flexural strength

All the beams of conventional and recycled aggregate concrete were tested for flexural under central point load in a universal testing machine. A dial gauge to measure the deflection of the beams was arranged (Figure 9). Under gradually increasing load both deflection and failure load were recorded. These parameters are listed in Table 4.

TABLE 1: Details of batches

Batch	**No of cubes**	**No of beams**	**Cement (kg)**	**Marble dust (kg)**	**F.A (kg)**	**NCA (kg)**	**RCA (kg)**	**Water (kg)**
B1	3	3	43.73	0.00	97.18	75.93	75.93	21.87
B2	3	3	42.64	1.09	97.18	75.93	75.93	21.87
B3	3	3	41.55	2.19	97.18	75.93	75.93	23.62
B4	3	3	40.45	3.28	97.18	75.93	75.93	24.49
B5	3	3	39.36	4.37	97.18	75.93	75.93	26.24

TABLE 2: UPV testing of specimens

Batch	Specimen#1			Specimen#2			Specimen#3		
	Time (μs)	Velocity(m/s)		Time (μs)	Velocity (m/s)		Time (μs)	Velocity (m/s)	
		S-Waves	P-Waves		S-Waves	P-Waves		S-Waves	P-Waves
1	29.3	2218.5	4437	30.2	2152.5	4305	29.8	2181.0	4362
2	31.4	2070.0	4140	30.8	2110.5	4221	32.0	2031.5	4063
3	30.7	2117.5	4235	31.2	2083.5	4167	31.3	2076.5	4153
4	30.7	2117.5	4235	32.2	2018.5	4037	30.0	2166.5	4333
5	31.8	2044.0	4088	31.7	2050.5	4101	31.2	2083.5	4167

TABLE 3: Failure load and compressive strength

Batch	**Specimen.1**		**Specimen.2**		**Specimen.3**	
	Load (KN)	**Strength (N/mm^2)**	**Load (KN)**	**Strength (N/mm^2)**	**Load (KN)**	**Strength (N/mm^2)**
1	1102.00	48.98	800.10	35.56	1099.80	48.88
2	870.40	34.24	831.80	28.08	867.90	34.13
3	997.20	44.32	888.60	39.49	900.40	40.02
4	824.20	36.63	846.40	37.62	846.00	37.60
5	815.20	36.23	751.40	33.40	879.50	39.09

TABLE 4: Failure load and deflection in beams

Beams	**Specimen 1**		**Specimen 2**		**Specimen 3**	
	Max. Load	**Deflection**	**Max. Load**	**Deflection**	**Max. Load**	**Deflection**
	(N)	**(mm)**	**(N)**	**(mm)**	**(N)**	**(mm)**
1	42141	2.90	38614	2.10	33508	1.80
2	37128	2.71	30817	2.30	30538	1.60
3	29795	2.50	29610	1.95	33972	2.70
4	27289	1.95	36200	2.10	32859	1.93
5	38799	1.86	31930	1.87	35736	2.10

Fig. 8: Cube testing

Fig. 9: Beam testing

4 Results and Discussion

4.1 Modulus of elasticity

Time and velocity results obtained from ultrasonic pulse velocity testing by PUNDIT and presented earlier are used to compute the modulus of elasticity of all samples. The obtained results are presented in Table 5. It may be observed that the modulus of elasticity of conventional concrete is in the range of the modulus of elasticity of concrete reported in the literature [28]. Whereas, the modulus of elasticity of recycled concrete recorded is less than that of conventional concrete. However, due to the introduction of marble dust in recycled aggregate concrete, an improvement in the parameter is observed. It is further observed that the reduction in the parameter for all considered cement replacement with marble dust ash is up to 15%. With replacement levels of 5% and 7.5%, the reduction in the value is the same but beyond this replacement level, the value is reduced further.

The modulus of elasticity may also be computed as the function of compressive strength as reported by ACI-318 [29] and Chao et al. [28]. The numerical expressions given by both references are reproduced as under for clarity of the reading and are used to evaluate the modulus of elasticity using the compressive strength results presented in the previous section.

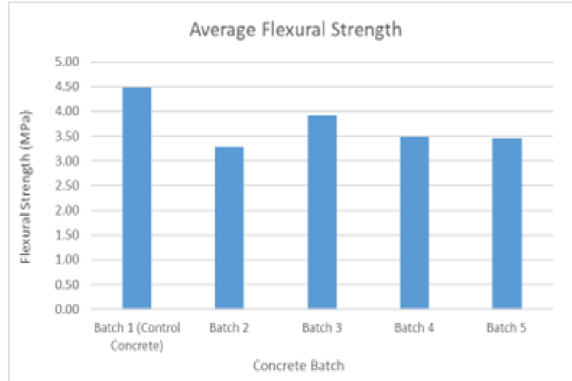

Fig. 10: Average flexural strength

$$E_c = 4730\sqrt[2]{f_c'} \;\; ACI-318 \tag{4}$$

$$E_c = 22000\sqrt[2]{f_c'} \;\; Chao\ et.al. \tag{5}$$

f_c' in both equations is the compressive strength of concrete in MPa. The average results obtained from the above equations along with those presented in Table 5 are compared in Table 6. It may be observed that the modulus of elasticity computed from UPV results is in good agreement with those obtained by using the ACI-318 equation for normal concrete. Whereas the equation developed by Chao et al. [29] predicts about 15% higher values. Hence it may be concluded that the addition of marble dust in recycled aggregate concrete shows improvement and not only the UPV testing but also the ACI-318 equation for normal concrete can comfortably be used for recycled aggregate concrete with marble dust ash up to 7.5%.

4.2 Flexural strength

Test results of beam samples of all five batches for flexure were presented in the previous section. The maximum load recorded is then used to evaluate flexural strength using the ASTM [30] formula given below. The obtained results for each batch are averaged and shown in Figure 10.

$$f_S = \frac{3PL}{2bd^2} \tag{6}$$

It may be observed that all batches of proposed concrete observed a reduction in flexural strength, however, all the results fall within the range of the parameter specified by ACI-318 [29]. The comparison of the flexural strength of the proposed concrete with the control concrete is shown in Figure 11. Considering

TABLE 5: Modulus of elasticity by UPV

Batch	Sample	Poisson's Ratio (ϵ)	Shear Modulus (G)	Modulus of Elasticity	Average
			GPa	GPa	
1	1	0.33	12.21	32.55	31.59
	2	0.33	11.54	30.76	
	3	0.33	11.80	31.46	
2	1	0.33	10.24	27.31	27.45
	2	0.33	10.73	28.63	
	3	0.33	9.90	26.41	
3	1	0.33	10.85	28.94	27.99
	2	0.33	10.33	27.55	
	3	0.33	10.31	27.48	
4	1	0.33	10.72	28.58	28.00
	2	0.33	9.66	25.75	
	3	0.33	11.12	29.66	
5	1	0.33	9.94	26.52	26.88
	2	0.33	10.05	26.80	
	3	0.33	10.24	27.32	

TABLE 6: Comparison of modulus of elasticity

Batch	Modulus of Elasticity (GPa)		
	UPV	ACI-318	Ref [28]
B1	31.59	31.54	36.18
B2	27.45	26.82	32.47
B3	27.99	30.39	35.29
B4	28.00	28.88	34.11
B5	26.88	28.47	33.79

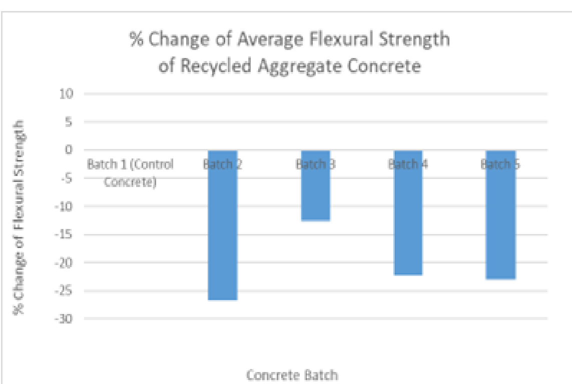

Fig. 11: Change of Average flexural strength

the strength loss of control concrete as zero it may be observed that induction of marble dust powder in recycled aggregate concrete resulted in the loss of strength from 12% to 26%. At the dosage of 2.5% loss of strength is recorded more but it lowered at 5% replacement and then again increased approximately at the same level for both 7.5% and 10% dosages of marble dust. Therefore, a cement replacement level of 5% with marble dust and 50% replacement of conventional coarse aggregates with coarse aggregates from demolishing waste is considered suitable with respect to the flexural strength of recycled aggregate concrete as the residual strength at this replacement level is 88%. It is further observed that the obtained results of this research work for flexural strength are better compared to those reported by Yang et al. [31]. The failure of a typical beam is shown in Figure 12. It started from the top fiber almost at the center and moved vertically towards the bottom fiber. The failure of other specimens was also similar. Due to plain concrete, the failure pattern was anticipated which is true even for concrete with recycled aggregates and marble dust.

Central deflection at the time of the failure was also recorded. The average values of the specimens within the batch along with percentile deviation with respect to batch 1 specimens (control concrete) are listed in Table 7. The deflection of individual specimens of all batches is displayed in Figure 13. It may be observed that the deflection in specimens with recycled material deviated from the deflection of control specimens. It is due to the presence of recycled aggregates and marble dust. It may be observed that the deflection of the

Fig. 12: Failure of beam

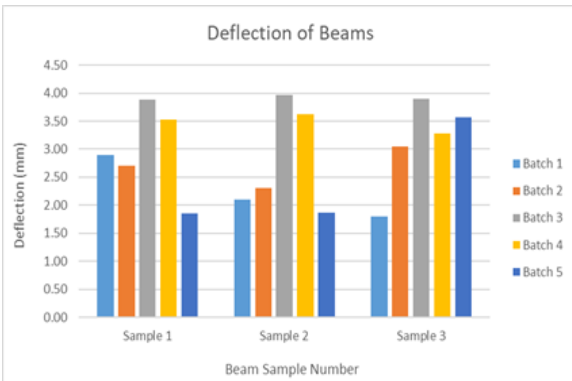

Fig. 13: Deflection of beam

specimens both conventional and recycled aggregate concrete remained less than the approximate maximum deflection in beams allowed by ACI – 318 [29]. It may further be observed that the average deflection in samples other than the batch 2 samples remained less than the average deflection of control specimens. This shows that the presence of marble beyond 5% makes concrete stiffer and brittle leading to sudden failure. Although it is anticipated that the presence of reinforcing steel in concrete may resolve the issue to much extent, brittle failure is to be avoided. Therefore, 5% replacement of cement with marble dust is considered suitable along with 50% recycled aggregates.

The results of the present laboratory investigations show that both recycled aggregates from demolishing waste and marble dust have promising effects on the concrete, particularly flexural strength. Hence 50% and 5% replacement of conventional coarse aggregates and cement respectively with demolishing waste and marble dust are concluded as optimum values.

TABLE 7: UPV testing of specimens

Beams	Deflection (mm)	% Change with Batch 1	Flexural Strength (MPa)	% Change with Batch 1
1	2.27	–	4.48	–
2	2.20	-2.79	3.28	-26.65
3	2.38	5.15	3.91	-12.58
4	1.99	-12.06	3.48	-22.28
5	1.94	-14.26	3.45	-22.94

5 Conclusion

From the comparison of the laboratory investigations presented in this research article following are concluded.

1) UPV testing and numerical equation of ACI-318 for determination of modulus of elasticity can also effectively be used for the concrete with recycled aggregates and marble dust.
2) 5% dosage of the marble dust as cement replacement in recycled aggregate concrete gives 88% residual flexural strength.
3) Central deflection of concrete beams at above-mentioned dosage of marble dust is only 5% more than that of control concrete.
4) Central deflection of all concrete beams remained within the limits of maximum allowable deflection by ACI-318.

Therefore, based on the outcome of this study it may be concluded that 5% replacement of cement with marble dust in recycled aggregate concrete containing 50% dosage of recycled aggregates is optimum. However, fine-tuning the dosage of the marble dust is recommended for the possible betterment of the results.

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