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Effect of Metakaolin on Non-destructive Parameters of Recycled Aggregate Concrete

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ABSTRACT

This research work investigates the influence of incorporation of metakaolin (MK) on compressive strength and Non-destructive characteristics (Ultrasonic pulse velocity and Rebound number) ofboth Natural aggregate concrete (NAC) and recycled aggregate concrete (RAC). The concrete mixes are produced with 100% RCA, as substitution ofNCA and 10%, 15% and 20% metakaolin, as partial replacement of Ordinary Portland Cement. The concrete mixes have been designed for M30 grade according to BIS codal procedures with water- to-binder ratio 0.43. The compressive strength,Ultrasonic pulse velocity and Rebound number of concrete mixes has been determined after 28 days of curing and compared with the result of control concrete (Concrete with 0% RCA and Metakaolin). From the results of the study, a degradation in Ultrasonic pulse velocity(UPV) and Rebound number (RN)value is detected on replacing NCA with RCA, which is enhanced by incorporating MK up to 15%.

KEYWORDS

Compressive strength, Construction and Demolition (C & D), Metakaolin, Recycled coarse aggregate, Rebound number, Ultrasonic pulse velocity

INTRODUCTION

Now a days, concrete has been used extensively in the construction industry to full fill huge requirement in the field of growing civilization and urbanization. The enormous use of concrete in construction sectoris responsible for several environmental problems like depletion of natural aggregates, energy consumption,and CO_2 emission. Besides, the activities like activities like destruction, reconstruction and rehabilitationsof various concrete structures generates large amount of construction and demolition (C & D) waste every year.The area required for land-filling this amount of waste is enormous. Therefore, recycling of construction and demolition waste is important, to reduce the amount of open spacerequired for land-filling as well as to preserve the environment through conservationof resource. The concept of recycling these waste concrete by crushing and sieving concrete pieces to produce Recycled coarse aggregates (RCA) has become auseful alternative in construction sector to reduce the need for natural aggregates, minimize the waste disposal problems and helps in preservation of the environment. However, the use of RCA to produce recycled aggregate concrete (RAC) is still not popular due to poor properties of RCA. Previous experiments carried out on RAC indicate that attached mortar is responsible for its poorer properties as it, increases water absorption, reduces the densityand also leads to higher porosity(Çakir, 2014). So RAC containing RCA possesses poor performance in terms of mechanical and durability properties as compared to natural aggregate concrete (NAC)(Bravo et al, 2015; Mukharjee and Barai, 2014).Previous literature showed that the change in compressive strength (CS) of RACis very less when the replacement of aggregates was within 30% and afterthat the compressive strength decreases (Mehfteh et al., 2013). The compressive strength of RAC was reduced up to 30% at 100% replacement of RCA with NCA(Tam et al.,2005).Similarly, the flexural strength and split tensile strength was decreased up to 18% and 16% for different content of RCA(Wardeh et al., 2015). The non-destructive parameters of concrete like Ultrasonic pulse velocity (UPV) and Rebound number (RN) also decreased by using RCA (Rao et al.,2011). The durability Properties like drying shrinkage and creep coefficients also vary directly with variation in the content of RCA (Tam et al.,2015).

For enhancing the qualities of RCA several techniques were adopted by many researcherssuch as removal of adhered mortar of the RCA (Wang et al., 2017), strengthening of adhered mortar of RCA (Xuan et al. 2016), two stage mixing approach (Li et al., 2012)and use of mineral admixtures such as metakaolin, fly ash, silica fume, and GGBFS as replacements of cement (Radonjanin et al., 2013). Moreover, the utilization of metakaolin in RAC greatly enhances the mechanical and durability characteristics by its pozzolanic and filler effect.

Metakaolin (MK) is a pozzolanic material obtained by calcination of kaolinitic clay at a temperature ranging between 500 °C and 800 °C. Metakaolin in concrete reacts with $Ca(OH)_2$ and produces additional CSH gel which enhances the properties of RAC. Again, the filler effect of finer particles of metakaolin enhances the early age strength and durability properties by filling voids of RAC and (Siddique and Klaus, 2009).The earlier studies showed that the compressive strength, split tensile strength and chloride penetration resistance was significantly enhanced by using 10% MK in RAC (Kapoor et al., 2017; Radonjanin et al., 2013). Some other research works documented that the use of 15% MK improved the mechanical as well as durability properties of RAC (Kou et al., 2011).

The present study examines the effect of incorporation of RCA and metakaolin on compressive strength and non-destructive properties of concrete. Concrete mixes has been preparedwithNCA and 100% RCA along with different percentage of metakaolin (0%, 10%, 15% and 20%). The compressive strength, UPV and RN of all the mixes has been determined after 28 days and relationship among the above mentioned properties has been established to access the influence of metakaolin in RAC.

EXPERIMENTAL PROGRAM

The binding materials used in the present investigation were Ordinary Portland Cement (OPC) of 43 grade satisfying the requirements of IS: 8112-1989 and metakaolin, collected from Kaomin industries, Gujarat, India. The properties of metakaolin such as fineness and specific gravity were found to be 12600cm^2/gm and 2.64 respectively. The properties of cement were determined by performing various standard tests and furnished in table1.

Table 1. Properties of Cement

Specific gravity	Fineness (cm^2/gm)	Setting times (min)		Consistency (%)	Mortar strength (MPa)		
		initial	final		3 days	7days	28days
3.15	3200	65	275	32	24.23	33.53	45.30

Locally available siliceous type river sand and 20 mm crushed granite type aggregate were natural fine aggregate (NFA) and Natural coarse aggregate (NCA) respectively, for producing all concrete mixes. The recycled coarse aggregates used in the studywere 20 mm granite type aggregate with adhered cement mortar collected by crushing waste concrete pieces from the roof of a demolished building near Angul, India. Standard tests were conducted to determine the properties of aggregates and presented in Table 2. Normal drinking water free from deleterious materials was used for both casting and curing of specimens.

Table 2. Properties of aggregates

Type of aggregate	Specific gravity	Fineness modulus	Bulk density (kg/m^3)		Impact value (%)	Crushing value (%)	Abrasion value (%)	Water absorption (%)
			Loose	Compact				
NFA	2.63	3.21	1548	1666	-	-	-	0.8
NCA	2.85	6.95	1577	1792	14.3	20.5	17.28	0.36
RCA	2.35	7.00	1336	1505	20.23	29.2	32.4	4.32

To achieve the aim of research work, total 8 concrete mixes were prepared by taking NCA and RCA and OPC aws partially replaced with metakaolin at 0%, 10%, 15% and 20% replacement level. The control mix was designed for M30 grade concrete with water-binder-ratio 0.43.The concrete mixes are designed assuming the aggregates were at surface saturates dry (SSD) condition. So adjustment in water content was made to full fill the extra water requirement of aggregates depending on the water absorption. Three 150mm cubes were casted for each mix and cured under water in fully submerged condition up to the testing ages. The compressive strength was determined on 150mm cube with compressive strength testing machine of 2000 kN capacity after 28 days curing according to IS: 516 1959. The UPV and RN test was performed on 150mm cubes by using UPV measuring instrument and Schimdt hammer after 28 days curing.The details of materials and mix proportions are given in Table 3.

Table 3. Mix proportions of concrete mixes per 1 m^3 of concrete

Mix	MK (%)	RCA (%)	Cement (kg)	MK (kg)	NFA (kg)	NCA (kg)	RCA (kg)	Water (kg)
NA1	0	0	420	0	668	1232	0	181
NA2	10	0	378	42	668	1232	0	181
NA3	15	0	357	63	668	1232	0	181
NA4	20	0	336	84	668	1232	0	181
RA1	0	100	420	0	668	0	1016	207
RA2	10	100	378	42	668	0	1016	207
RA3	15	100	357	63	668	0	1016	207
RA4	20	100	336	84	668	0	1016	207

RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH

Fig.1 represents the results of compressive strength of NAC and RAC after 28 days curing. It is observed that after 28 days of curing the compressive strength of control mix is found as 40.43 MPa. When metakaolin is included at 10%, 15% and 20% the enhancement in compressive strengths are recorded as 44.48 MPa, 45.36 MPa and 43.82 MPa which are 10%, 12.2% and 8.4% higher than control concrete.

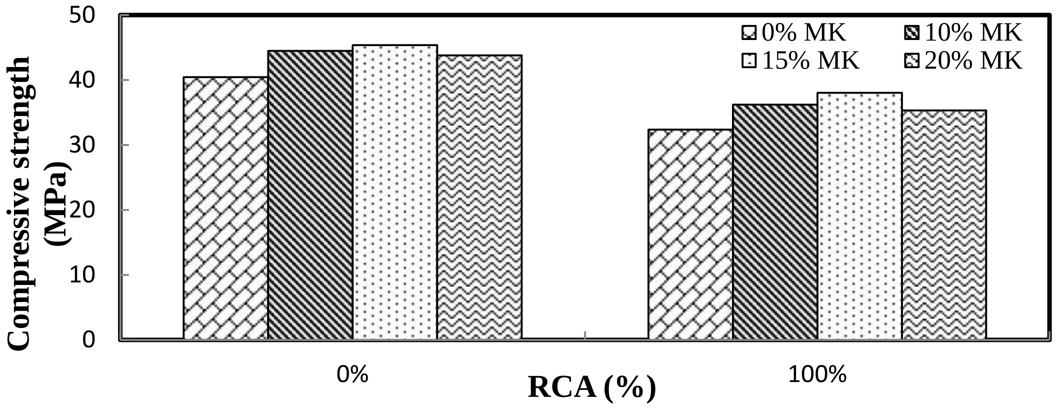

Fig 1:Variation in 28 days compressive Strength

Similarly, the compressive strength of fully RAC is 32.35MPa which is 20% lower than the control mix. On incorporation of metakaolin at dosages of 10%, 15% and 20% the compressive strength of RAC is improved to 36.22 MPa, 38.05 MPa and 35.31 MPa which are 12%, 17.6% and 9.1% higher than RAC without metakaolin. The increase in compressive strength may be due to the pozzolanic effect metakaolin resulting the formation of additional C-S-H gel. Similar trend of strength development is observed at 28 days as that obtained for 7 days. The rate of strength enhancement is lower at 20% metakaolin; however the compressive strength at 20% is higher than corresponding control concrete.

ULTRASONIC PULSE VELOCITY (UPV)

Fig. 2demonstrates the results of ultrasonic pulse velocity(UPV) test after 28days curing. It is seen that at 0% of RCA i.e for control concrete the UPV is found as 4983 m/s which reduces to 4601 m/s for concrete with100% RCA. The reduction in UPV is due to higher porosity of RAC owing to the presence of old porous mortar on surface of RCA. However, when metakaolin is included at 10% ,15% and 20%, the UPV of NAC increases to 5145m/s, 5093m/s, 5043m/s and RAC increses to 4762m/s, 4823 m/s, 4688 m/s respectively. This enhancement in UPV is attributed to the densification of microstrucre of both RAC and NAC due to the formation of CSH gel in the pores by pozzolanic reaction of metakaolin.

Fig. 3represents the relationship between 28-day compressive strength and UPV. From this, it can be observed that UPV is directly propertional proportional to the compressive strength. The relationship between compressive strength and UPVfound from the regression analysis is given by

UPV = 42.967(28-day CS) + 3180.6

Since the R^2 value is 0.96 (greater than 0.90) , a strong relationship exists between the experimental values.

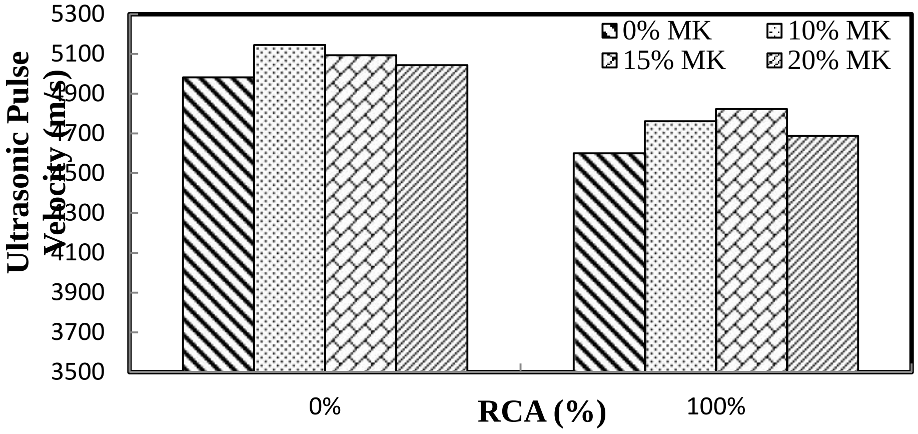

Fig. 2: Variation of Ultrasonic pulse velocity.

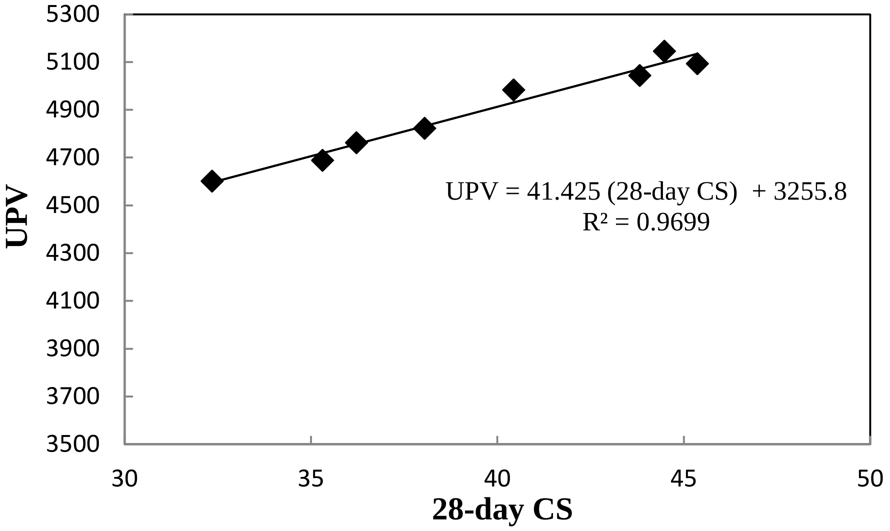

Fig. 3 Relationship between UPV and Compressive strength

REBOUND NUMBER

Fig. 4 illustrates the results of rebound number (RN) test. From this, it can be observed that the rebound number of concrete mixes at 0% and 100% RCA are 32.34 and 27.7 respectively.This reduced RN value for 100% RCA may be due to higher porosity and low density of RCA producing concrete of lesser hardnedsurface. However, a greater improvement in RN is observed by introducing metakaolin at 10%, 15%, and 20% on both RAC and NAC enhancing the RN to 34.21,34.85 and 32.92 respectively for NAC and 30.8, 31.76 and 29.82 respectively for RAC. This enhancement in RN values may be due to the pozzolanic reaction and pore filling ability of metakaolin particles resulting densified micro-structure.

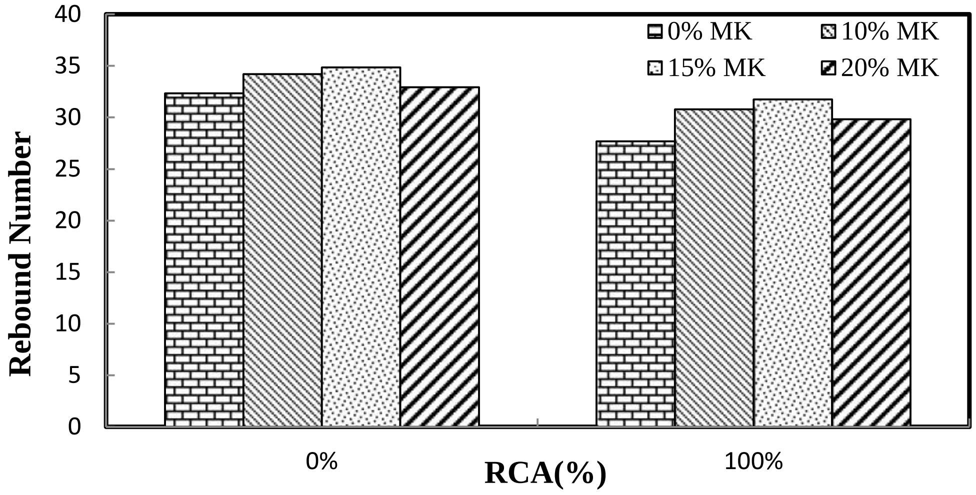

Fig 4: Rebound number for concrete mixes.

Fig. 5shows the relationship between 28-day compressive strength and Rebound number. It can be is found that like UPV, RN also varies directly with compressive strength. The relationship between compressive strength and UPV found from the regression analysis and an equation is obtained to relate compressive strength with RN that is

$$RN = 0.5031(28\text{-day CS}) + 11.76$$

The value of R^2 is 0.9432,so a good correlation is observed between 28-day compressive strength and Rebound number.

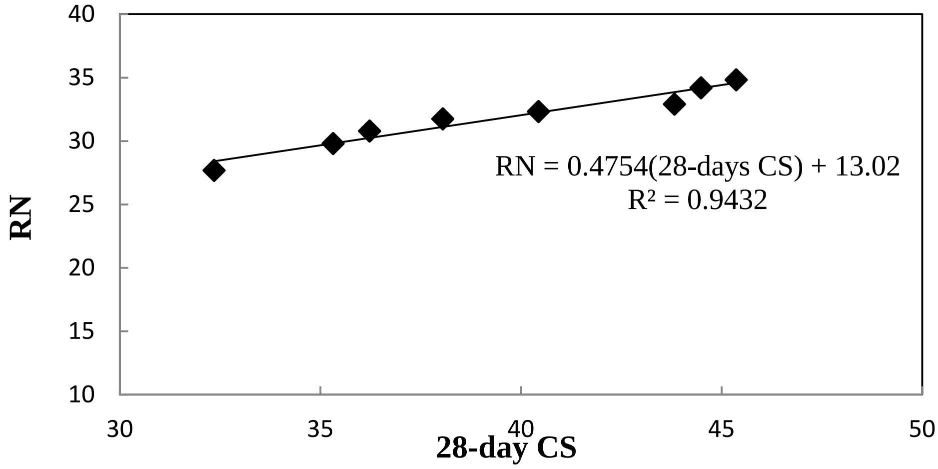

Fig. 5 Relationship between RN and Compressive strength

CONCLUSION

From the above experimental work, the effect of metakaolin on compressive strength and non-destructive test results (Ultrasonic pulse velocity and Rebound number) of both RAC and NAC is studied and the conclusions extracted from the above study are given below:

- The compressive strength of concrete reduces by using RCA in place of NCA due to lower quality of RCA.
- The compressive strength of both RAC and NAC improves by incorporating metakaolin at different percentage attaining optimum value at 15%.
- The UPV value of RAC is lower than NAC due to higher porosity, which shows an increament on incorporation of metakaolin at varying percentage.
- The RN value of both NAC and RAC enhances by adding metakaolin attaining optimum value at 15% replacement level.
- Both UPV and RN shows linear relationship with compressive strength and the equations obtained are in good aggrement with the experimental results.

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