International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 4
April 2018

Effect of Metakaolin on Compressive Strength of Recycled Aggregate Concrete

Rakesh Muduli
Veer Surendra Sai University of Technology, Burla, Sambalpur, Odisha, India
Bibhuti Bhusan Mukharjee
Veer Surendra Sai University of Technology, Burla, Sambalpur, Odisha, India

ABSTRACT

This experimental work investigates the effect of incorporation of metakaolin (MK) on compressive strength of both Natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) at different curing ages.Recycled aggregate concrete (RAC) mixes are prepared with 100% RCA, as substitution of NCA and 10%, 15% and 20% metakaolin, as partial replacement of Ordinary Portland Cement. The concrete mixes have been designed for M30 grade by following BIS codal procedures with water- to-binder ratio 0.43. The compressive strength of concrete mixes has been determined after 7, 28, and 90 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 of compressive strength is detected on replacing NCA with RCA at all curing ages, which is improved further by incorporating MK up to 15%. However, faster strength improvement is observed during early ages of curing.

KEYWORDS

Compressive strength, Construction and Demolition(C & D), Metakaolin, Recycled coarse aggregate

INTRODUCTION

In present scenario, concrete has been used as a major construction material due to its reliability in terms of strength, durability and economic considerations. The enormous use of concrete in construction industry, owing to rapid growth of industrialization and civilization creates several environmental problems like exhaustion of natural aggregates and CO_2 emission. On the other hand, a huge amount of construction and demolition(C & D) wastes are being generated annually due to demolition, reconstruction and mentainance workwhich creates serious problems like shortage of land for waste disposal and increase in the cost of transportation and its disposal. Therefore, to mitigate the aforementioned problems, it becomes necessary to develop an alternative construction material, thereby maintaining the sustainability of the environment. The concept of recycling i.e. crushing and sieving the waste concrete to produce Recycled coarse aggregates (RCA) has become a viable alternative in constructive world to reduce the need for natural aggregates, minimize the waste disposal problems and helps in preservation of the environment. However, use of RCA in producing recycled aggregate concrete (RAC) is still limited due to several drawbacks associated with it. The previous literatures in the field of recycled aggregate concrete (RAC); show that the properties of RCA are inferior to the NCA due to presence old adhered mortar on its surface

(Kou et al., 2012). SoRAC,prepared with RCA generally shows 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 studies indicated that no significant change in compressive strength (CS) of RACwas observed when the replacement of aggregates was within 30% and beyond this limit 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 reduction in flexural strength and split tensile strength was up to 18% and 16% for different content of RCA(Wardeh et al., 2015). Other 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, use of metakaolin in RAC significantly improvedthe mechanical and durability properties 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. The reaction of Metakaolin with $Ca(OH)_2$, produces additional CSH gel at ambient temperature which improves the properties of RAC. Also, the finer particles of metakaolin enter in to the voids of RAC and enhances the early age, strength as well as durability properties (Siddique and Klaus, 2009).Several previous studies related to the effect of MK in RAC revealed that the compressive strength and split tensile strength was significantly enhanced by using 10% MK in RAC(Radonjanin et al., 2013; Singh and Singh, 2016).Some other findings revealed that the use of 15% MK improved the mechanical as well as durability properties of RAC (Kou et al., 2011).

The present work tries to demonstrate the effect of incorporation of recycled coarse aggregate and metakaolin on workability and compressive strength of concrete at different curing ages. Concrete mixes containing natural coarse aggregates and 100% recycled coarse aggregates along with varying percentage of metakaolin(0%, 10%, 15%and 20%) has been prepared. The compressive strength of all the mixes has been determined after 7, 28, and 90 days to access the influence of metakaolinin RAC.

EXPERIMENTAL PROGRAM

The cement used in the present investigation was Ordinary Portland Cement (OPC) of 43 grade satisfying the requirements of IS: 8112-1989.Metakaolin was 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 table 1.

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 river sand of Zone-II and crushed granite type aggregate were used as natural fine aggregate (NFA) and Natural coarse aggregate (NCA) respectively, for producing all concrete mixes. The recycled coarse aggregates used in the study, was obtained by crushing waste concrete pieces from the roof of a demolished building near Angul, India. Standard tests were conducted to characterize the aggregates and presented in Table 2. Normal municipality 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 objective of the investigation, total 8 concrete mixes were prepared by substituting NCA with RCA at 0% and 100% replacement level and OPC 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 in accordance with the procedures of IS 10262: 2009.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 for different curing ages 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 7, 28 and 90 days curing according to IS: 516: 1959. The details of materials and mix proportions are given in Table 3.

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

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

RESULTS AND DISCUSSION

The variation of workability of Natural aggregate concrete (NAC) mixes and recycled aggregate concrete (RAC) mixes with respect to metakaolin (%) is provided in Fig. 1. The slump of control mix is found to be 75 mm which increases to 88mm for fully RAC. The increase in workability is due to the presence of additional water during mixing to compensate the water absorption of RCA. When metakaolin is incorporated at 10%, 15% and 20% by weight of cement in both NAC and RAC the slump value decreases slightly to 72mm,72mm,70mm for NAC and 86mm, 85mm and 81mm for RAC respectively. The decrease in slump is due to higher surface area of metakaolin.

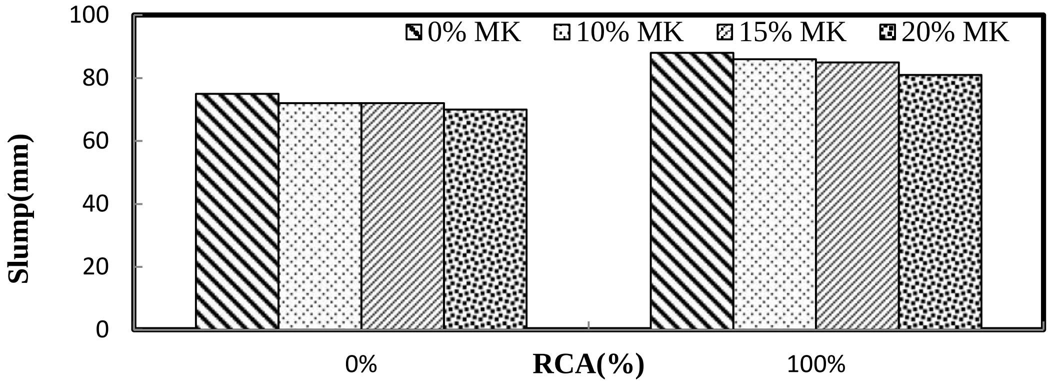

Fig. 1: Workability of concrete mixes

Fig.2 represents the results of compressive strength after 7 days curing.It is observed that after 7 days of curing the compressive strength of control mix is found as 31.36 MPawhich reduces to 25.87 MPa for fully RAC without metakaolin.This 17.5 % reduction in compressive strength is attributed to the lower properties of RCA. However, incorporation of metakaolin at 10%, 15% and 20% replacement level in both NAC and RAC improves the compressive strength to 34.34MPa, 35.32 MPa, 34.31 MPa for NAC and 28.94 MPa, 30.65 MPa, 28.82 MPa for RAC, which are 9.2%, 12.6%, 9.4% and 11.9%, 18.5%, 11.4% higher than corresponding concrete without metakaolin.The increase in compressive strength may be due to the pozzolanic effect and filler effect of metakaolin. It is also noticed that the optimum 7days compressive strength of both NAC and RAC are achieved at 15% metakaolin addition, however, the rate of strength development is higher in RAC than NAC.

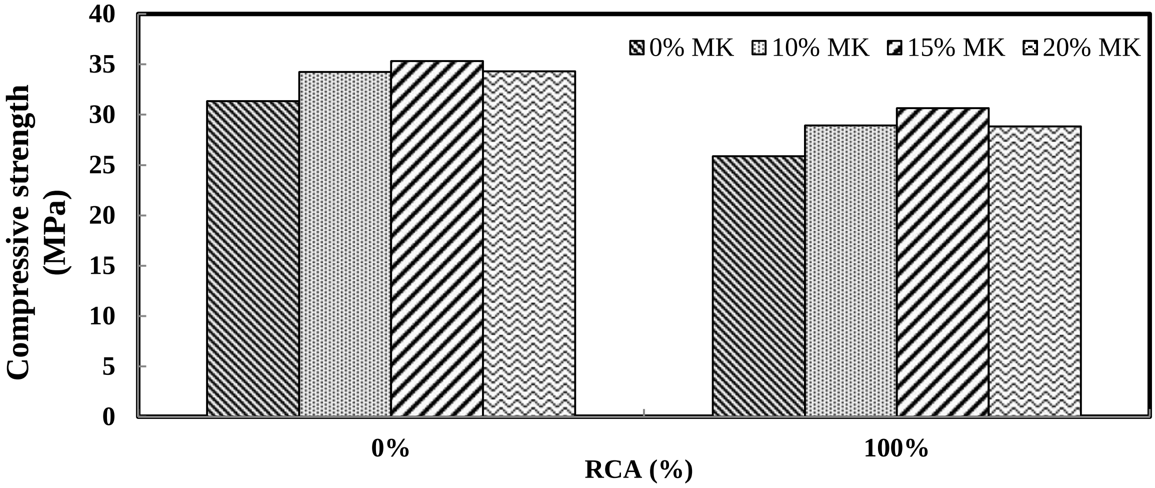

Fig. 2: Variation in 7 days compressive strength

Fig.3 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. 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.

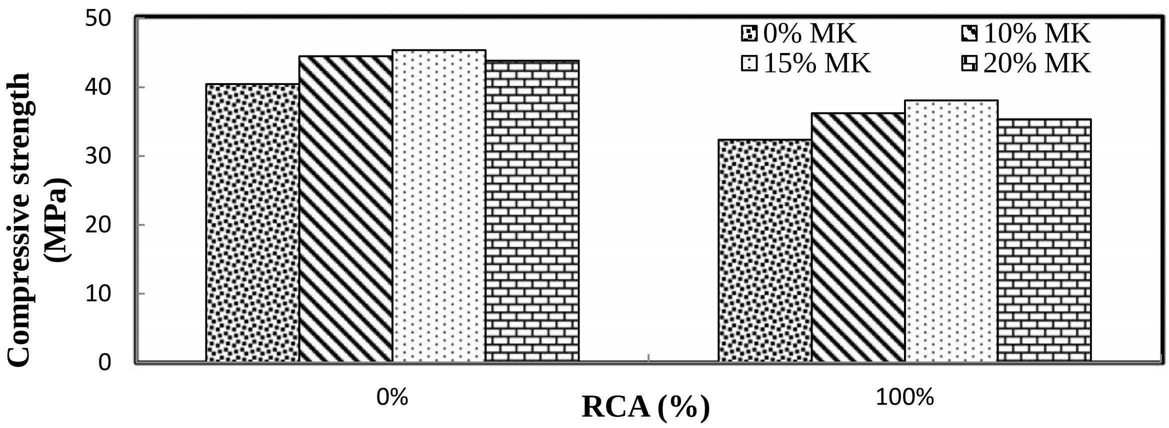

Fig 3: Variation in 28 days compressive strength

Fig.4demonstrates the results of compressive strength of concrete mixes after 90 days curing. It is found that after 90 days of curing the control mix possesses a compressive strength of 44.67MPawhich becomes 48.32 MPa, 48.72 MPa and 46.23 MPa at 10%, 15% and 20% metakaolin addition respectively. The above mentioned compressive strengths are 8.2%, 9.1% and 3.5% higher than control concrete, which are much less than the rate of strength development of 7 and 28 days.Similarly, the compressive strength of fully RAC is 37.8MPa which is 15.4% lower than the control mix. On incorporation of metakaolin, at dosages of 10%, 15% and 20% the compressive strength of RAC improved to 40.73MPa, 42.35MPa and 38.85MPawhich are 7.8%, 12% and 2.8% higher than RAC without metakaolin. It is seen that the rate of strength development at 90 days is much lower than early ages (7 and 28 days).This is because of slower rate of hydration at latter age, resulting the production of less amount of CH, available for pozzolanic reaction.The rate of 90days strength enhancement is also less at 20% metakaolin.

The relationship of 28-days CS with 7-days CS and 90-days CS is demonstrated in Fig. 5. From the best fit curve, it is observed that the relationship of 28-days CS with 7-days CS and 90-days CS is linear having R^2 values 0.98 and 0.97 (greater than 0.90) respectively. This indicates that a strong relationship exists between 28-days CS, 7-days CS and 90-days CS.

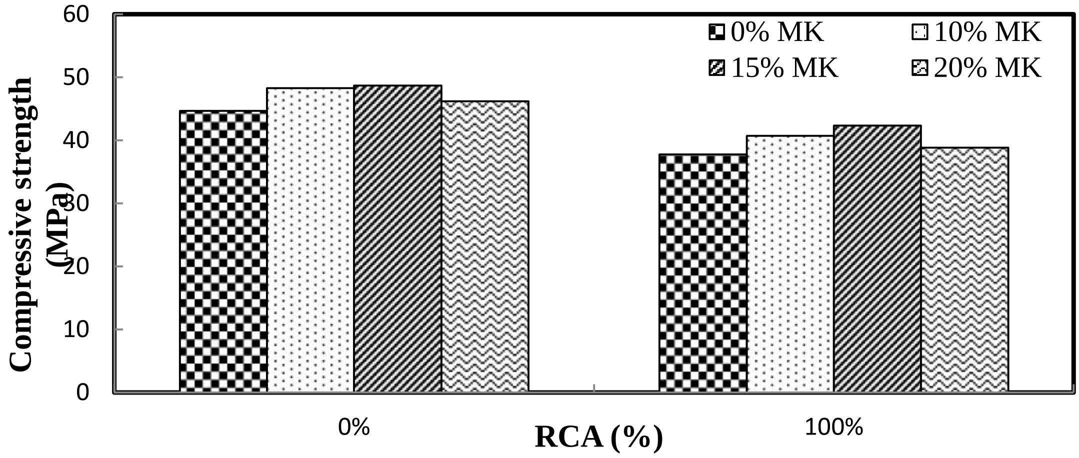

Fig 4 :Variation in 90 days compressive strength

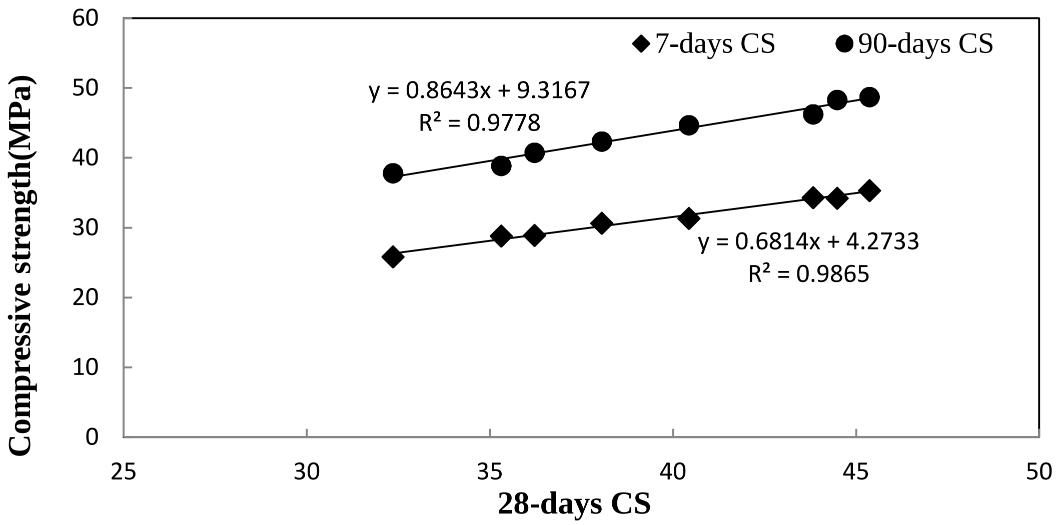

Fig. 5: Relationship between 28-days CS, 7- days CS and 90-days CS

CONCLUSION

From the above experimental work, the effect of metakaolin on properties of recycled aggregate concrete is studied and the conclusions drawn from the above study are listed below:

- The workability of concrete increases by substituting NCA with RCA due to presence of initial free water in mix. However slump value reduces by adding metakaolin to the concrete mix.
- 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 is improved by incorporating metakaolin at different percentage for all curing ages
- The optimum rate of strength development is observed up to 15 % metakaolin replacement level, after that the rate of strength development reduces.
- The compressive strength of RAC after 28 days of curing containing 15% metakaolin is similar to that of reference mix which indicates that sustainable concrete containing RCA and metakaolin can be produced with similar strength as that of NAC.
- The rate of strength development is higher at early ages than 90 days.

REFERENCE

[1] bravo, m., de brito, j., pontes, j., and evangelista, l. 2015. mechanical performance of concrete made with aggregates from construction and demolition waste recycling plants. j. clean. prod. 99, 59–74.

[2] kou, s.c., poon, c.s.and agrela, f. 2011. comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. cem. concr. compos. 33, 788–795.

[3] kou, s.c., poon, c.s., and wan, h.w. 2012. properties of concrete prepared with low-grade recycled aggregates. constr. build. mater. 36, 881–889.

[4] li, w., xiao, j., sun, z., kawashima, s. and shah, s.p. 2012. interfacial transition zones in recycled aggregate concrete with different mixing approaches. constr. build. mater. 35, 1045–1055.

[5] mefteh, h., kebaïli, o., oucief, h., berredjem, l.and arabi, n. 2013. influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened concrete. j. clean. prod. 54, 282–288.

[6] mukharjee, b.b. and barai, s. v. 2014. influence of nano-silica on the properties of recycled aggregate concrete. constr. build. mater. 55, 29–37.

[7] radonjanin, v., malešev, m., marinković, s.and al malty, a.e.s. 2013. green recycled aggregate concrete. constr. build. mater. 47, 1503–1511.

[8] siddique, r. and klaus, j. 2009. influence of metakaolin on the properties of mortar and concrete: a review. appl. clay sci

[9] singh, n.and singh, s.p. 2016. carbonation and electrical resistance of self compacting concrete made with recycled concrete aggregates and metakaolin. constr. build. mater. 121, 400–409.

[10] tam, v.w.y., kotrayothar, d. and xiao, j. 2015. long-term deformation behaviour of recycled aggregate concrete. constr. build. mater. 100, 262–272.

[11] tam, vivian w.y., g.x. and tam, c.m. 2005. micro-structural analysis of recycled aggregate concrete produced from two-stage mixing approach. cem. concr. res. 35, 1195–1203.

[12] wang, l., wang, j., qian, x., chen, p., xu, y.and guo, j. 2017. an environmentally friendly method to improve the quality of recycled concrete aggregates. constr. build. mater. 144, 432–441.

[13] wardeh, g., ghorbel, e. and gomart, h. 2015. mix design and properties of recycled aggregate concretes: applicability of eurocode 2. int. j. concr. struct. mater. 9, 1–20.

[14] xuan, d., zhan, b. and poon, c.s. 2016. assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates. cem. concr. compos. 65, 67–74.