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Effect of Rice Husk Ash on the Compressive Strength and Permeation Resistance of Concrete

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ABSTRACT: *In order to support the use of rice husk ash as a supplementary cementitious material, this paper investigated the effect of partial replacement of Portland cement with up to 50% contents of rice husk ash on the compressive strength and permeation resistance of concrete. Compressive strength at 7, 14, 21 and 28 days and initial surface absorption after 10 minutes and void content at 28, 60 and 90 days of Portland cement and rice husk ash blended cement concretes were determined to standards at the water/cement ratios of 0.35, 0.50 and 0.65 and analysed at the 28-day compressive strengths of 20-50 N/mm^2. At equal water/cement ratios, compressive strength reduced by 1.02% and initial surface absorption and void content increased by 0.79 and 0.87% respectively for a unit replacement of Portland cement with rice husk ash. Equal strengths with the conventional Portland cement concrete were achieved by the blended cement concretes at lower water/cement ratios and the required water/cement ratios reduced with increasing content of rice husk ash. Also, at equal strengths, all the blended cement concretes have lower initial surface absorption and void content values and therefore higher resistance to permeation than the conventional Portland cement concrete. Hence, the use of rice husk ash would not impair the strength and permeation resistance of concrete.*

KEYWORDS: *concrete, compressive strength, initial surface absorption, permeation resistance, rice husk ash.*

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I. INTRODUCTION

In order to produce cheaper and more environmentally compatible concrete, by-products of industrial and agricultural wastes, with intrinsic hydraulicity, have been suggested as partial replacements for Portland cement in concrete. Examples of these by-products of industrial wastes are fly ash, silica fume, ground granulated blast furnace slag, metakaolin and limestone powder [1-4] while relevant information on by-products of agricultural wastes such as sawdust ash, rice husk ash, corncob ash, groundnut husk ash, oil palm residue ash, bagasse ash, cassava peel ash and bamboo leaf ash are provided in Ogunbode and Akanmu [5], Umoh and Odesola [6] and Raheem and Kareem [7]. However, while cement and concrete standards have supported the use of the by-products of industrial wastes, none of the by-products of the agricultural wastes has been recognised by these standards. This is probably because less extensive research works have been carried out on the by-products of the agricultural wastes. Hence, this paper is intended at providing more information on the suitability of rice husk ash as a supplementary cementitious material.

Rice husk ash (RHA) is a by-product of rice husk which is an agricultural waste from the production of rice. With about 100 million tonnes of rice husk yielding 20% (about 20 million tonnes) of RHA per year [8], enough RHA would be available for use in concrete. Rice husk ash is produced when rice husk is calcined. Depending on the calcination temperature and duration of burning, RHA with amorphous or crystalline silica content would result [9]. The amorphous form is obtained at temperatures below 800oC while the crystalline form is obtained at temperatures between 800 and 900oC [10]. Pozzolans with high amount of amorphous silica is characterised by high pozzolanic reaction resulting in additional calcium silicate hydrates to improve concrete performance [11, 12]. It is also not impossible to have both the amorphous and crystalline forms at temperatures far lower than 800oC if the burning period is prolonged [12]. Hence, in such situation, while the amorphous form would contribute to the pozzolanic reaction to produce additional calcium silicate hydrates, the crystalline form would produce the filler effect to produce a concrete with dense microstructure [12]. However, for high pozzolanic reactivity, the amorphous form would be preferred to the crystalline form for concrete work. Since the amorphous RHA is calcined at temperatures lower than that of PC (about 1700oC), its use would also reduce the energy consumption and emissions associated with the use of PC in concrete. Furthermore, the use of RHA in concrete would reduce the need for landfill sites and therefore contribute to solving the disposal problem and proper management of rice husk waste.

The partial replacement of PC with RHA, at equal water/cement ratios, would reduce the compressive strength of concrete with increasing content [13, 14]. Like every pozzolan, while RHA will reduce strength development at early ages, the pozzolanic reaction with increasing curing age will result in concrete with strength comparable with that of the conventional concrete at later ages [10]. The use of RHA will also reduce the porosity and increase the resistance of concrete to chemical attack from deleterious materials [15, 16]. Hence, for good concrete strength and durability performance, a range of 10-40% has been suggested for the RHA content of concrete [8, 10, 17-20].

The durability of concrete (ability of concrete to resist deterioration while in use) would depend on its resistance to permeation. This is because if the deleterious materials are prevented from entering concrete, the durability of concrete would be preserved. One of the transport mechanisms for assessing the permeation resistance of concrete is the initial surface absorption. The initial surface absorption is a means of assessing the resistance of the surface of concrete against water penetration [2, 21]. Hence, initial surface absorption after ten minutes (ISAT-10) which according to BS 1881-208 [21] is sufficient for assessing the resistance of the surface of concrete to a pressure of water equivalent to that of driving rain has been adopted in this research. Resistance to permeation also depend on the porosity (volume of voids) of concrete [22-24]. Hence, due to the dearth of literature on the permeation resistance of RHA blended cement concrete, this paper investigated the effect of RHA on the compressive strength, ISAT-10 and void content of concrete.

II. MATERIALS AND METHODS

The cements used in this investigation were Portland cement (PC, 42.5 strength class) and rice husk ash (RHA). Using an average of 400-800oC used by Jongpradist et al. [8], RHA was calcined to a maximum of 600oC and left at this temperature for about 5 hours. The ash was cooled to room temperature and sieved with 75µm sieve. The properties of the cements are presented in Table 1. Sand was used as fine aggregates and 19 mm granite chippings were used as coarse aggregates.

Concrete was designed using the Building Research Establishment guide [25] and prepared in accordance with BS EN 12390-2 [26] at a free water content of 210 kg/m3 and water/cement ratios of 0.35, 0.50 and 0.65 using potable water conforming to BS EN 1008 [27]. Mapefluid N200 conforming to BS EN 934-2 [28] was used as superplasticiser to obtain a concrete with S2 consistence (slump of 50-90 mm) in accordance with BS EN 206-1 [29]. Compressive strength, initial surface absorption after 10 minutes and void content were obtained for PC concrete and RHA blended cement concrete at 10, 20, 30, 40 and 50% contents of RHA. Compressive strength was determined at 7, 14, 21 and 28 days in accordance with BS EN 12390-3 [30] using 100 mm cubes. Initial surface absorption and void content were determined at 28, 60 and 90 days in accordance with BS 1881-208 [21] and ASTM C642 [31] respectively using 150 mm cubes. Detailed descriptions of the initial surface absorption and void content tests are presented in Folagbade and Olatunji [32].

Table 1:Properties of Portland cement and rice husk ash

Property	PC	RHA
Particle density, g/cm^3	3.15	2.14
Oxide composition, %		
CaO	63.2	2.7
SiO_2	19.7	86.4
Al_2O_3	4.7	1.7
Fe_2O_3	3.2	0.8
MgO	2.3	1.2
MnO	0.4	0.2
TiO_2	0.1	-
K_2O	0.6	2.9
Na_2O	0.5	0.5
P_2O_5	0.2	0.6
Cl	0.1	-
SO_3	3.4	0.3
LOI	2.4	4.3
$SiO_2 + Al_2O_3 + Fe_2O_3$		88.9

III. RESULTS AND DISCUSSION

Effect of RHA on compressive strength of concrete at different water/cement ratios

The compressive strengths of PC and RHA blended cement concretes at different curing ages, RHA contents and water/cement ratios are illustrated in Fig. 1. The Figure shows that compressive strength of concrete increased with increasing curing age due to increasing hydration products and decreased with increasing water/cement ratio (due to decreasing content of cement) and increasing content of RHA. This result agrees with Madandoust et al. [13] and Marthong [14]. Also, except the 50PC+50RHA mix at the water/cement ratio of 0.65, most of the mixes achieved 28-day compressive strengths of not less than 20 N/mm^2 which is the minimum compressive strength required for structural concrete.

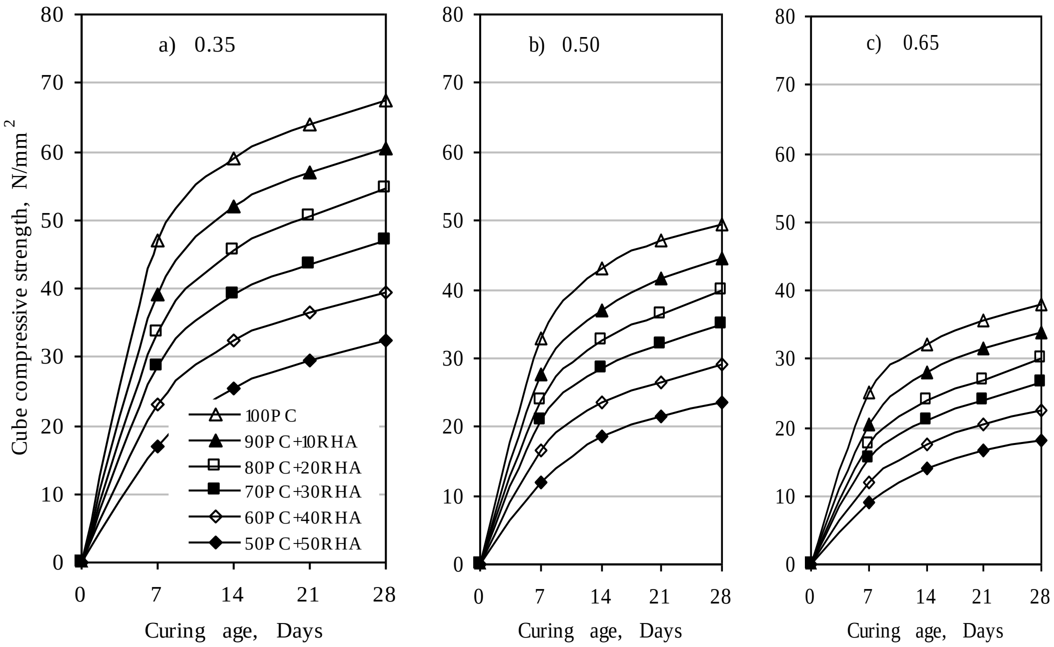

Fig. 1: Compressive strength of concretes at different water/cement ratios

Table 2 presents the compressive strength factors of concretes (percentages of compressive strengths of concretes with respect to the compressive strength of 100PC concrete) at the ages of 7, 14, 21 and 28 days. The strength factors of the blended cement concretes reduced with increasing content of RHA and increased with increasing curing age. The disparities between the strength factors of the 100PC concrete and the blended cement concretes reducing with increasing curing age show that the pozzolanic reaction of RHA improves with increasing curing age. The Table shows that the 28-day compressive strength of concrete reduced respectively by 10.43, 19.83, 29.97, 41.23 and 52.34% at 10, 20, 30, 40 and 50% contents of RHA. This amounts to a reduction of 0.99-1.05% (with an average of 1.02%) for a unit replacement of PC with RHA.

Effect of RHA on ISAT-10 and void content of concrete at different water/cement ratios

The ISAT-10 and void content of PC and RHA blended cement concretes at different curing ages, RHA contents and water/cement ratios are illustrated respectively in Fig.2 and 3. The Figures show that ISAT-10 and void content of concrete decreased with increasing curing age due to increasing hydration products and increased with increasing water/cement ratio (due to decreasing content of cement) and increasing content of RHA.

Table 3 presents the ISAT-10 factors of concretes (percentages of ISAT-10 of concretes with respect to ISAT-10 of 100PC concrete) at equal ages of 28, 60 and 90 days. Compared with PC, the ISAT-10 factors show that the resistance to surface absorption of concrete reduced with increasing content of RHA. The disparities between the ISAT-10 factors of the 100PC concrete and the blended cement concretes reducing with increasing curing age show that the pozzolanic reaction of RHA improves with increasing curing age. The Table shows that the 28-day ISAT-10 of concrete increased by 8.98, 17.64, 23.12, 27.45 and 35.28% at 10, 20, 30, 40 and 50% contents of RHA. Consequently, ISAT-10 increased respectively by 0.90, 0.86, 0.77, 0.69 and 0.71 for a unit replacement of PC with RHA. This amounts to an increase of 0.69-0.90% (with an average of 0.79%) for a unit replacement of PC with RHA.

Table 2:Compressive strength factors of concretes

Mix	w/c	Compressive strength factor, %					
		d7	d14	d21	d28	d28 Average	28d Disparity
	0.35	100	100	100	100		
100PC	0.50	100	100	100	100	100	-
	0.65	100	100	100	100		
90PC	0.35	82.98	88.14	89.06	89.63		
+	0.50	83.33	86.05	88.30	89.60	89.57	10.43
10RHA	0.65	82.00	85.94	88.73	89.47		
80PC	0.35	71.28	77.12	78.91	80.74		
+	0.50	72.73	75.58	77.66	80.81	80.17	19.83
20RHA	0.65	70.00	75.00	76.06	78.95		
70PC	0.35	60.64	66.10	67.97	69.63		
+	0.50	63.64	66.28	68.09	70.71	70.03	29.97
30RHA	0.65	62.00	65.63	67.61	69.74		
60PC	0.35	48.94	55.08	57.03	58.52		
+	0.50	50.00	54.65	56.38	58.59	58.77	41.23
40RHA	0.65	48.00	54.69	57.75	59.21		
50PC	0.35	36.17	43.22	46.09	48.15		
+	0.50	36.36	43.03	45.74	47.47	47.66	52.34
50RHA	0.65	36.00	43.75	46.48	47.37		

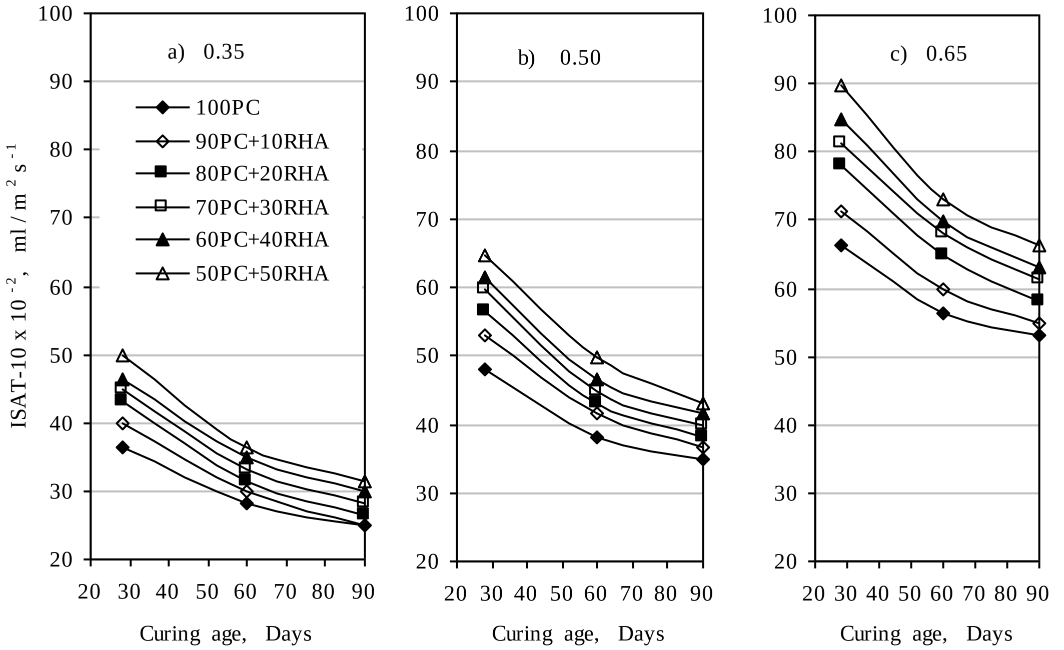

Fig. 2: ISAT-10 of concretes at different water/cement ratios

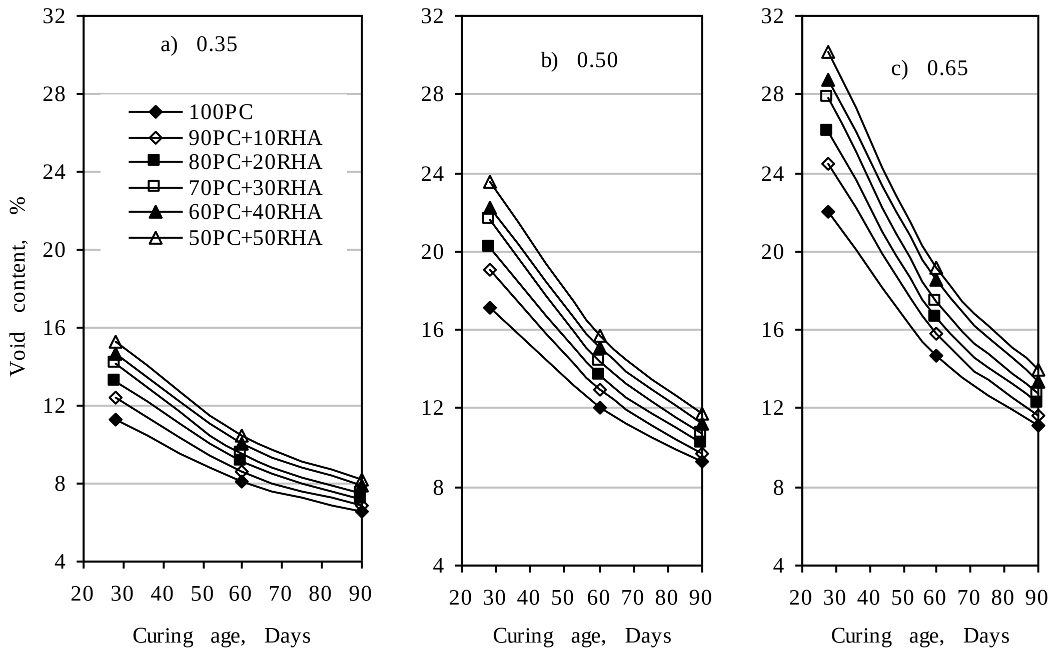

Fig. 3: Void content of concretes at different water/cement ratios

Table 3: ISAT-10 factors of concretes

Mix	w/c	ISAT-10 factor, %				
		d28	d60	d90	d28 Average	28d Disparity
100PC	0.35	100	100	100	100	-
	0.50	100	100	100		
	0.65	100	100	100		
90PC + 10RHA	0.35	109.09	105.88	100.00	108.98	+8.98
	0.50	110.34	108.70	104.76		
	0.65	107.50	105.88	103.13		
80PC + 20RHA	0.35	118.18	111.76	106.67	117.64	+17.64
	0.50	117.24	113.04	109.52		
	0.65	117.50	114.71	109.38		
70PC + 30RHA	0.35	122.73	117.65	113.33	123.12	+23.12
	0.50	124.14	117.39	114.29		
	0.65	122.50	120.59	115.63		
60PC + 40RHA	0.35	127.27	123.53	120.00	127.45	+27.45
	0.50	127.59	121.74	119.05		
	0.65	127.50	123.53	118.75		
50PC + 50RHA	0.35	136.36	129.41	126.67	135.28	+35.28
	0.50	134.48	130.43	123.81		
	0.65	135.00	129.41	125.00		

Table 4 presents the void content factors of concretes (percentages of void content of concretes with respect to void content of 100PC concrete) at equal ages. Compared with Portland cement, the void content factors show that the porosity of concrete would increase with increasing content of RHA.The disparities between the void content factors of the 100PC concrete and the blended cement concretes reducing with increasing curing age also confirm that the pozzolanic reaction of RHA improves with increasing curing age. The Table shows that the 28-day void content of concrete increased by 10.92, 18.12, 25.89, 30.14 and 36.62% at 10, 20, 30, 40 and 50% contents of RHA. Consequently, void content increased respectively by 1.09, 0.91, 0.86, 0.75 and 0.73 for a unit replacement of PC with RHA. This amounts to an increase of 0.73-1.09% (with an average of 0.87%) for a unit replacement of PC with RHA.

Thepercentage reductionin ISAT-10 and void content per unit replacement of PC with RHA reduced with increasing total replacement level. Hence, RHA has the ability to improve the microstructure of concrete with increasing content. This feat would be attributable to the spherical particle shape of RHA [18, 33] and the filling ability of the crystalline silica that may be present in the RHAat that calcination temperature and duration of burning [12] leading to a denser microstructure and increase in permeation resistance.

Table 4: Void content factors of concretes

Mix	w/c	Void content factor, %				
		d28	d60	d90	d28 Average	28d Disparity
	0.35	100	100	100		
100PC	0.50	100	100	100	100	-
	0.65	100	100	100		
90PC	0.35	110.85	107.32	105.04		
+	0.50	111.03	107.52	104.88	110.92	+10.92
10RHA	0.65	110.88	107.20	105.05		
80PC	0.35	117.97	113.03	109.01		
+	0.50	118.11	113.18	110.03	118.12	+18.12
20RHA	0.65	118.28	113.04	110.63		
70PC	0.35	125.62	118.86	114.50		
+	0.50	125.87	118.95	115.04	125.89	+25.89
30RHA	0.65	126.17	118.61	115.14		
60PC	0.35	130.34	125.06	121.07		
+	0.50	129.88	125.59	120.69	130.14	+30.14
40RHA	0.65	130.20	125.82	120.72		
50PC	0.35	136.03	129.78	125.34		
+	0.50	137.10	130.08	125.96	136.62	+36.62
50RHA	0.65	136.73	130.03	125.50		

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Effect of RHA on ISAT-10 and void content of concrete at different 28-daycompressive strengths

Concrete is specified on the basis of the 28-day strength by designers. Hence, interpolating the experimental values, Table 5 presents the 28-day ISAT-10 values and void contents of concretes at the 28-day strengths of 20-50 N/mm^2. The Table presents 27 concrete options (four 100PC concretes at different water/cement ratios and 23 blended cement concretes at different contents of RHA and water/cement ratios). Cross deduction from the Table shows that ISAT-10 and void content reduced with increasing strength. This is because the lower the water/cement ratio (characterised by higher cement content at constant water content) the higher the strength achievable. Hence, higher resistance to permeation would occur with increasing strength or reducing water/cement ratio. Also, since all the mix combinations at up to 50% content of RHA would achieve a minimum compressive strength of 20 N/mm^2 at 28 days at one water/cement ratio or the other, RHA blended cement concrete would be suitable for structural works.

Table 5 also shows that equal strengths with 100PC concrete were achieved by the RHA blended cement concretes at lower water/cement ratios. This is also in line with previous studies on other supplementary cementitious materials by Folagbade and Newlands [3] and Folagbade [34] among others. Also, at equal strengths, all the RHA blended cement concretes have lower ISAT-10 values and void contents than the 100PC concrete. These values reduced with increasing content of RHA at equal strengths. This also confirms that RHA has the propensity to increase the permeation resistance of concrete with increasing content. As earlier stated, the increase in permeation would due to the spherical particle shape of RHA [18, 33] as opposed to the angular particle shape of PCand the filling ability of the crystalline silica that may be present in the RHA [12]leading to better packing ability and denser microstructure of the blended cement concrete.

IV. CONCLUSION

This paper investigated the effect of RHA on the compressive strength, initial surface absorption and void content of concrete and the following conclusions have been drawn.

- At equal water/cement ratios, compressive strength reduced and ISAT-10 and void content of concrete increased with increasing content of RHA.
- Equal strengths with 100PC concrete were achieved by the RHA blended cement concretes at lower water/cement ratios and these water/cement ratios reduced with increasing content of RHA. Generally, ISAT-10 and void content of concrete reduced with increasing strength. Also, at equal 28-day compressive strengths, all the RHA blended cement concretes at up to 50% content of RHA have lower ISAT-10 and void content values than 100PC concrete.

Since concrete is specified on the basis of the 28-day compressive strength in practice, the partial replacement of PC content of concrete with RHA would result in blended cement concrete with better permeation resistance and suitable for structural works. Hence, the use of RHA in concrete will reduce the disposal problem of rice husk and contribute to the sustainability principle in concrete construction. However, further research is required on the embodied carbon-dioxide content (environmental compatibility) and cost for comparison with other pozzolans recognised by cement and concrete standards to justify its inclusion in the standards.

Table 5: ISAT-10 and void content of concretes at different 28-day strengths

28-day compressive strength, N/mm^2	Mix combination	w/c	ISAT-10 x 10^{-2}, ml/m^{2}s^{-1}	Void content, %
20	50PC+50RHA	0.57	75.12	24.46
25	50PC+50RHA	0.46	59.78	18.69
	60PC+40RHA	0.58	72.78	23.82
	70PC+30RHA	0.68	86.45	30.13
30	50PC+50RHA	0.38	51.99	15.98
	60PC+40RHA	0.48	58.95	18.53
	70PC+30RHA	0.58	70.44	23.09
	80PC+20RHA	0.65	78.02	26.08
35	50PC+50RHA	0.32	48.01	14.78
	60PC+40RHA	0.40	50.54	15.74
	70PC+30RHA	0.50	59.76	18.83
	80PC+20RHA	0.56	64.07	20.55
	90PC+10RHA	0.63	68.66	23.19
	100PC	0.70	73.96	25.16
40	60PC+40RHA	0.34	45.78	14.49
	70PC+30RHA	0.43	51.96	16.10
	80PC+20RHA	0.50	56.44	17.67
	90PC+10RHA	0.55	58.65	18.81
	100PC	0.61	60.88	19.83
45	70PC+30RHA	0.37	46.43	14.50
	80PC+20RHA	0.44	50.13	15.43
	90PC+10RHA	0.49	52.08	16.22
	100PC	0.55	53.49	16.95
50	70PC+30RHA	0.32	42.63	13.69
	80PC+20RHA	0.39	45.89	14.05
	90PC+10RHA	0.44	47.21	14.51
	100PC	0.49	48.00	14.61

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