Recycled Aggregate as Coarse Aggregate Replacement in Concrete Mixes

Suraya Hani Adnan[1], Ismail Abdul Rahman[1], Hamidah Mohd Saman[2]

[1]Faculty of Civil and Environmental Engineering, UTHM, Malaysia; suraya@uthm.edu.my
[2]Faculty of Civil Engineering, UiTM, Malaysia

ABSTRACT: Utilization of Recycled Aggregate in concrete has been employed due to awareness of society in natural resources protection. The application of Recycled Aggregate (RA) as coarse aggregate in concrete mixes has been iniated as to make use effectively the waste materials. However the concrete using Recycled Aggregate or familiarly known as Recycled Aggregate Concrete has obtained lower performance compared to concrete using Natural Aggregate. Thus, in this research, Micronised Biomass Silica (MBS) which is produced from rice husk has been used for improving the performance of Recycled Aggregate Concrete. Concrete specimens containing various percentages of Recycled Aggregate (0%, 25%, 50%, 75%,100%) and MBS (0%, 4%, 8%, 12%) has been prepared for laboratory works. From the laboratory works it was found that after 28 days, 12 % of MBS has the ability to enhance the performance of 100% Recycled Aggregate in concrete for compressive strength up to 17.20 % and reduce the water permeability coefficient and water penetration up to 47.10 % and 7.5 % respectively. Thus it can be stated that RAC containing MBS has better performance compared to RAC without MBS.

Keywords: Recycled Aggregate, Micronised Biomass Silica, compressive strength, water permeability coefficient, water penetration

INTRODUCTION

Construction industry is an active industry in Malaysia. This is due to gaining the aim for becoming as a developed country in 2020. However, the scarcity of reducing in natural resources has turn into main issue. This is owing to its basic ingredients for producing concrete like gravel and crushed granite which played a role as coarse aggregate. Thus, to preserve this source, the application of Recycled Aggregate (RA) for producing concrete is introduced.

Although RA has widely been used in some developed countries such as United

Kingdom, United States and Denmark, its utilization in Malaysia is assumed as new material in construction industry. Less interest in RA application is may due to some factors such as lack of review of RA performance in concrete and there is still sufficient supply in natural resources. The landfill area for construction waste has not been so critical in Malaysia. However, as a responsibility society, the application of RA in the construction industry to protect the natural resources is much significant.

Even though RA is becoming a good alternative material, there is still a weakness on its performance in concrete. In fresh concrete performance, it was found that concrete containing RA or known as Recycled Aggregate Concrete (RAC) obtained lower in workability compared to concrete using Natural Aggregate or known as Natural Aggregate Concrete (NAC) (Topcu and Sengel, 2004: Limbachiya 2004). For hardened concrete performance, i.e. compressive strength, it was recognised that RAC obtained lower in strength compared to NAC (Topcu and Sengel 2004: Fraaij *et al,* 2002: Kenai *et al.,* 2002 and Poon *et al*., 2004).

Thus, in this research, Micronised Biomass Silica (MBS) is used as cement replacement material in RAC mixes for improving the performance of RAC. This research is focused on the influence of various percentages of MBS in RAC on the performance in compressive strength, water permeability coefficient and water penetration.

EXPERIMENTAL WORK

Materials Used

In this research, these materials were used for experimental work. There are Ordinary Portland Cement (OPC), sand, natural gravel with maximum size 20mm and superplasticizer. Recycled Aggregate (RA) was prepared by crushing the waste cubes which have been thrown away at the outside of Material Laboratory of Universiti Tun Hussein Onn Malaysia (UTHM). The waste cubes without considering the age were collected and broken into smaller pieces by using hammer. Then it is crushed by using a jaw crusher. Maximum size of RA that has been produced is 20 mm and minimum size is 5 mm. Then, the Micronised Biomass Silica (MBS) was prepared by burning the rice husk in rotary reactor furnace. This furnace has been located at Material Laboratory in Universiti Tun Hussein Onn Malaysia (UTHM) and enables to synthesis any biomass silica material with different regime of temperature. In order to obtain an amorphous material, the temperature for rotary furnace is fixed at 500 ^{0}C. Off white amorphous material is obtained after one hour and about 50 gram of ash has been produced. Before that, rice husk is fed manually into the rotary furnace. Then, Jar Mill is used to produce finer biomass silica. After been grinding by Jar Mill for one hour, the particle size of MBS is reduced from 48 μm to 25.77 μm.

Concrete Mixes

Twenty concrete mixes were prepared and DOE method was adopted as design mix.

Table 1.0 illustrated the mix proportions for each series of concrete. The target strength of concrete at 28 days is 25 MPa, its water-cement ratio is 0.5 and its slump value is designed for 60mm-180mm. Superplasticizer also has been used to maintain the workability of concrete. For each concrete mix, three cubes were prepared and average reading was taken as data. Concrete also been cured in water until testing age.

Table 1.0 Mix Proportions for Concrete

Concrete Series	RA (%)	MBS (%)	Cement (kg/m^3)	Water (kg/m^3)	Coarse Aggregate (kg/m^3)		Fine Aggregate (kg/m^3)	SP (ml/kg^3)
					NA (kg/m^3)	RA (kg/m^3)		
Control Concrete	0	0	450	225	1115	0	892	4500
RA25	25	0	450	225	836	279	892	4500
RA50	50	0	450	225	558	558	892	4500
RA75	75	0	450	225	279	836	892	4500
RA100	100	0	450	225	0	1115	892	4500
M4	0	4	432	225	1115	0	892	4320
M4-RA25	25	4	432	225	836	279	892	4320
M4-RA50	50	4	432	225	558	558	892	4320
M4-RA75	75	4	432	225	279	836	892	4320
MBS4-RA100	100	4	432	225	0	1115	892	4320
M8	0	8	414	225	1115	0	892	4140
M8-RA25	25	8	414	225	836	279	892	4140
M8-RA50	50	8	414	225	558	558	892	4140
M8-RA75	75	8	414	225	279	836	892	4140
M8-RA100	100	8	414	225	0	1115	892	4140
M12	0	12	396	225	1115	0	892	3960
M12-RA25	25	12	396	225	836	279	892	3960
M12-RA50	50	12	396	225	558	558	892	3960
M12-RA75	75	12	396	225	279	836	892	3960
M12-RA100	100	12	396	225	0	1115	892	3960

- RA = RA content
- M = MBS content

Testing of Fresh Concrete

Slump test was applied to determine the workability of concrete. This test has been conducted according to BS 1881: Part 102: 1983.

Testing of Hardened Concrete

Performance of hardened concrete was assessing by using three tests which are compressive strength test, water permeability coefficient test and water penetration test. The compressive strength test was conducted according to BS 1881: Part 116. Water permeability coefficient and water penetration test were conducted according to ISO/DIS 7031 and DIN 1048 respectively.

RESULTS/DISCUSSION

Workability

Figure 1.0 shows the results of slump value for all concrete series. From this figure, it can be seen that concrete mixes with 100% RA and 12 % MBS attained lowest in slump value compared to other series of concrete. The control concrete obtained highest in slump value than that of other concrete mixes. From these results it is clearly showed that concrete mixes with RA incorporation obtained lower in slump value compared to control concrete. Thus it indicates that RA has higher water absorption properties compared to normal aggregate. On the other hand, concrete mixes with MBS also has lower slump value than that of concrete mixes without MBS. These results pointed out that MBS also does have water absorption properties. So, the concrete mixes with both RA and MBS employment have harsher and less cohesive properties which lead into difficulty in concrete compacting progress.

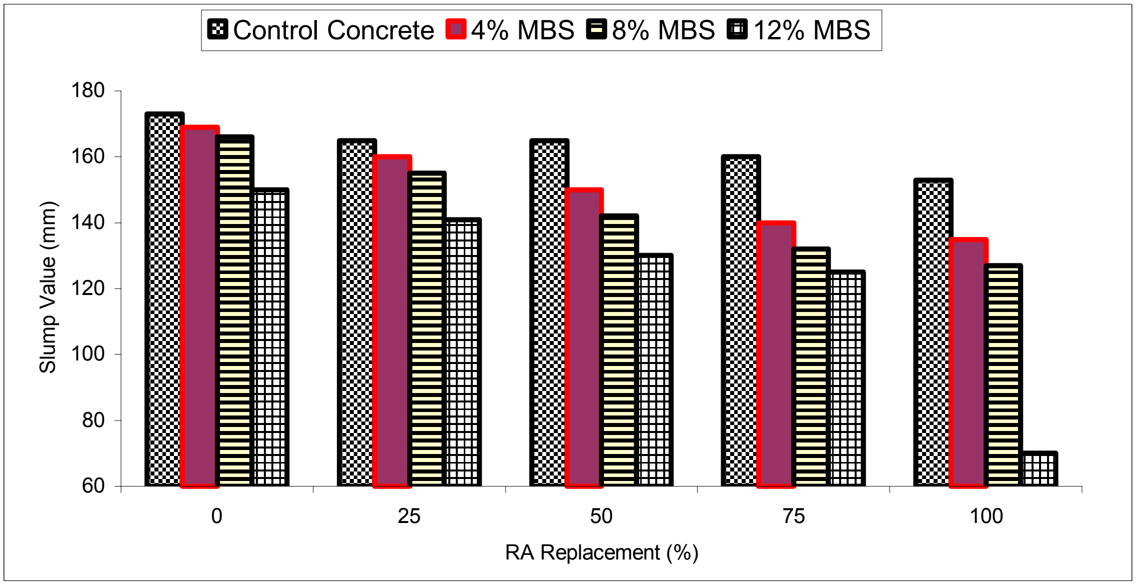

Figure 1.0 Slump value of concrete mixes with various percentages of RA and MBS

Compressive Strength

The results of compressive strength of concrete have been presented in Table 2.0. This table shows that M12 attained highest in compressive strength for all age of curing compared to other concrete. RA100 attained lowest in compressive strength than other corresponding for 28 days age of curing. From this table it can be seen that as MBS content increases, it compressive strength increases. And as RA content increases, its compressive strength decreases. Moreover, this table also indicates that MBS does enhancing the compressive strength of RAC. This is due to MBS contributes into pozzolanic reaction with calcium hydroxide, $Ca(OH)_2$ which is from the primary cement hydration process and forms additional calcium silicate hydrate, C-S-H gel. This reaction form the dense calcium silicate hydrate, C-S-H gel which has an ability to improve the Interfacial Transition Zone (ITZ) and densifying the pore structure inside the concrete that lead into enhancement of compressive strength in concrete (Toutanji *et al.,* 2004).

Table 2.0 Compressive Strength of Concrete with various percentages of RA and MBS

Mixes	Compressive Strength (MPa)		
	7 days	**14 days**	**28 days**
Control Concrete	20.00	0.00	22.00
25% RA	19.20	-4.00	21.70
50% RA	15.50	-22.50	21.90
75% RA	16.00	-20.00	18.60
100% RA	16.50	-17.50	18.90
4% MBS	24.00	28.00	32.40
4%MBS-25%RA	18.10	21.60	29.10
4%MBS-50%RA	23.30	28.90	30.40
4%MBS-75% RA	26.00	28.40	31.60
4%MBS-100% RA	25.00	29.70	30.50
8% MBS	24.80	32.10	37.50
8%MBS-25%RA	19.00	23.50	32.30
8%MBS-50%RA	24.80	32.10	33.90
8%MBS-75% RA	21.00	23.70	32.00
8%MBS-100% RA	25.60	30.50	31.70
12% MBS	29.80	34.10	39.00
12%MBS-25%RA	26.70	33.30	34.30
12%MBS-50%RA	28.20	34.10	36.10
12%MBS-75% RA	23.00	28.30	33.90
12%MBS-100% RA	27.80	33.60	35.40

Water Permeability Coefficient

Table 3.0 has tabulated the water permeability coefficient results. From the table, it can be seen that as RA content increases, its water permeability coefficient increases. And as MBS content increases, its water permeability coefficient decreases. Thus these results indicated that as RA content increases, the water permeability of concrete became worse and as MBS content is increases, the better its water permeability. These results also clearly showed that MBS has enhancing the water permeability of concrete containing RA. This is due to MBS which has calcium silicate hydrate, C-S-H gel that acts as a filler to fill-up the pores and Interfacial Transition Zone (ITZ) in RAC. As the pores and ITZ in the concrete was filled, it protects the concrete from water entering into that cause concrete to be prone to water permeability.

Table 3.0 Water Permeability Coefficient of Concrete with various percentages of RA and MBS

Mixes	Water Permeability Coefficient (m/s)		
	7 days	**14 days**	**28 days**
Control Concrete	1.04E-10	3.87E-11	1.50E-11
25% RA	1.10E-10	4.12E-11	1.85E-11
50%RA	1.21E-10	6.11E-11	1.98E-11
75% RA	1.77E-10	6.27E-11	2.15E-11
100% RA	2.08E-10	7.98E-11	2.40E-11
4% MBS	1.02E-10	2.67E-11	7.51E-12
4%MBS-25% RA	1.13E-10	3.20E-11	8.62E-12
4%MBS- 50%RA	1.16E-10	4.03E-11	8.72E-12
4%MBS -75% RA	2.41E-10	4.95E-11	8.84E-12
4%MBS -100% RA	2.85E-10	2.92E-11	9.54E-12
8% MBS	9.39E-11	2.56E-11	6.25E-12
8% MBS- 25% RA	7.84E-11	6.26E-11	6.99E-12
8% MBS- 50%RA	4.71E-11	1.03E-11	7.46E-12
8% MBS- 75% RA	3.53E-10	6.65E-11	7.81E-12
8% MBS- 100% RA	1.99E-10	1.24E-11	7.88E-12
12% MBS	3.60E-11	7.69E-12	4.56E-12
12% MBS- 25% RA	4.43E-11	9.38E-12	5.15E-12
12% MBS- 50%RA	4.57E-11	8.92E-12	6.26E-12
12% MBS- 75% RA	2.54E-10	6.95E-11	6.99E-12
12% MBS- 100% RA	1.06E-10	7.78E-12	7.94E-12

Water Penetration

Water penetration results for different series of concrete at age 28 days have been shown in Figure 3.0. From this figure it can be seen that concrete containing 12 % MBS and 0% RA obtained lowest in water penetration. On the other hand, concrete containing 100% RA and 0% MBS obtained highest in water penetration. It is also revealed that concrete containing RA lead into high water penetration. The reason is may be attributed to that RAC of having two ITZ. First ITZ is between RA and new cement paste namely as new ITZ and second ITZ, is between RA and old cement mortar attached namely as old ITZ (Kong *et al.,* 2010). Because of these ITZ presences in concrete, the large amount of pores and cracks were created which contribute into high water absorption. High water content requirement in new ITZ of RAC was resulted from this phenomenon which leads into high water permeability of the resulted concrete. However, MBS could overcome the inferiority performance due to RA inclusion by C-S-H gel formation which has an ability to fill up the ITZ and strengthen the ITZ (Poon *et al.,* 2004b and Li *et al.,* 2009) thus increase the resistance to water penetration.

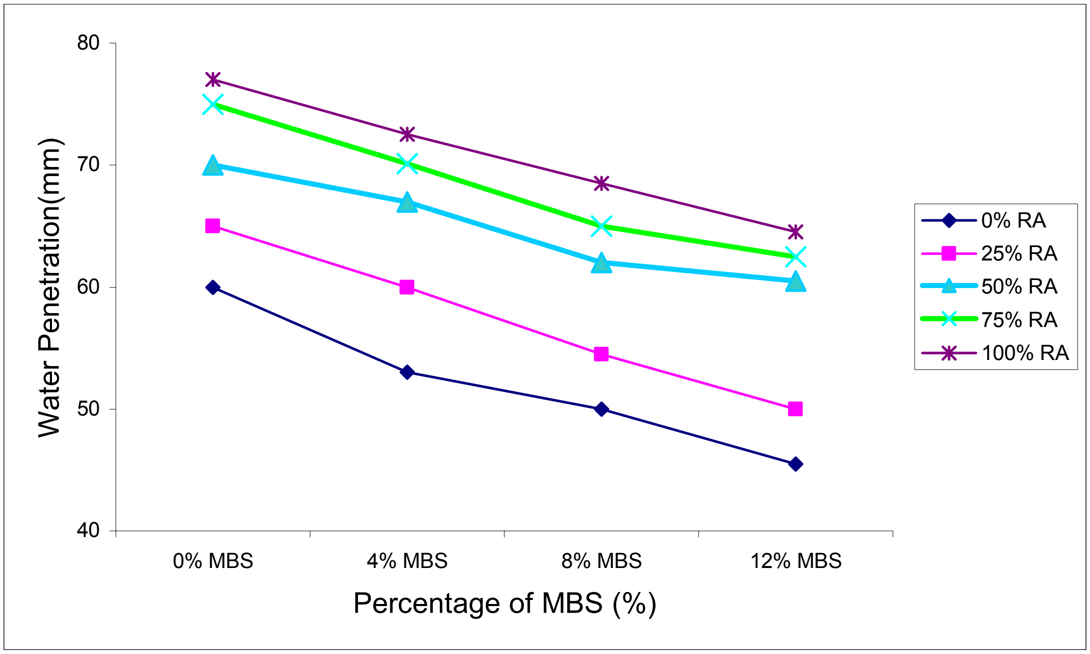

Figure 2.0 Water penetration for various percentages of RA and MBS

CONCLUSION

The conclusions from this research are listed as follows:

i) RAC with MBS obtained lower in slump value compared to RAC without MBS.
ii) RAC with MBS obtained higher in compressive strength than that of RAC without MBS.
iii) Water permeability of RAC with MBS is better compared to RAC without MBS.
iv) MBS can improve the performance of RAC in terms of compressive strength and water permeability.

REFERENCES

Topcu,I.B. & Sengel,S.(2004). "Properties Of Concretes Produced With Waste Concrete Aggregate*." Cement and Concrete Research*, 34(8), pp. 1307-1312.

Limbachiya, M.C. (2004). "Coarse Recycled Aggregates for Use in New Concrete." *Proceedings of the Institution of Civil Engineers, Engineering Sustainability.* 157 (ES2), pp. 99-106.

Fraaij,A.L., Pietersen, H.S. & Vries, J.(2002)."Performance of Concrete With Recycled Aggregates." *Proceedings of International Conference on Sustainable Concrete Construction*. University of Dundee, Scotland,UK, pp. 187-198.

Kenai,S., Debieb, F. & Azzouz,L. (2002). "Mechanical Properties and Durability of Concrete Made with Coarse and Fine Recycled Aggregate." *Proceedings of International Conference on Sustainable Concrete Construction*, University of Dundee, Scotland,UK, pp. 383-392.

Poon, C.S., Shui, Z.H. & Lam, L. (2004). "Effect of Microstructure of ITZ On Compressive Strength of Concrete Prepared With Recycled Aggregates." *Construction and Building Materials,* 18, pp. 461-468.

Toutanji,H.,Delatte,N.,Aggoun,S.,Duval,R. & Danson,A. (2004). "Effect of Supplementary Cementitious Materials on The Compressive Strength and Durability of Short-Term Cured Concrete*.* " *Cement and Concrete Research*, 34(2), pp. 311-319.

Kong, D., Lei, T., Zheng, J., Ma, C., Jiang, J. & Jiang, J. (2010). "Effect and Mechanism of Surface-Coating Pozzolanics Materials Around Aggregate On Properties and ITZ Microstructure of Recycled Aggregate Concrete." *Construction and Building Materials*, 24, pp.701-708.