Available online at www.sciencedirect.com
SCIENCE DIRECT
Cement and Concrete Research 36 (2006) 943 – 950
Cement and Concrete Research

Properties of HPC with recycled aggregates

Tsung-Yueh Tu [a,*], Yuen-Yuen Chen [b], Chao-Lung Hwang [a]

[a] Department of Construction Engineering, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Road, Taipei, 106, Taiwan, ROC
[b] Department of Architecture, Hwa Hsia Institute of Technology, 111, Gongjhuan Road, Jhonghe City, Taipei County 235, Taiwan, ROC

Received 18 March 2005; accepted 30 November 2005

Abstract

The utilization of recycled aggregates can minimize environmental impact and slow the huge consumption of natural resources used for concrete applications. However, recycled aggregates are not suitable for use in the production of High Performance Concrete (HPC) due to their relatively high absorption capacity, unstable properties and recycled aggregates' weaker strength. Such inadequacies can be overcome through carefully examining the characteristics of recycled aggregates and then adopting proper mixture proportions. In this paper, recycled aggregates generated from demolished-construction wastes were examined and the Densified Mixture Design Algorithm (DMDA) was applied in the design of HPC. Results show that HPC specimens containing recycled aggregates can be designed to have a slump of more than 180 mm and a slump-flow larger than 550 mm. However, HPC specimens with high amounts of recycled aggregates and cement added lose their high-flowing and self-consolidating characteristics after 1 h due to their greater water absorption. Local standards of durability were satisfied at the age of 91 days both by concrete resistivity and chloride ion penetration.

Keywords: Recycled aggregates; HPC; Durability

1. Introduction

Concrete, it has been claimed, is not an environmentally friendly material due to its destructive resource-consumption nature and severe environmental impact after its use. Nevertheless, it will remain one of the major construction materials being utilized worldwide. Taking the concept of sustainable development into consideration, the concrete industry has to implement a variety of strategies with regards to future concrete use, for instance; improvements in the durability of concrete and the better use of recycled materials. In general, aggregates occupy 55%~80% of concrete volume. Without proper, alternative aggregates being utilized in the near future, the concrete industry globally will consume 8~12 billion tonnes annually of natural aggregates after the year 2010 [1]. Such large consumption of natural aggregates will cause destruction of the environment. Therefore, to find and supply suitable substitutes for natural aggregates is an urgent task. Even though the utilization of recycled aggregates in the concrete industry has been taking place for many years, the promotion of this recycled material as an alternative has never been easy in the industry. Basically, recycled aggregates are seldom utilized in structural constructions, instead they have been used as fillers in road construction and in low-level applications due to material defects such as large water absorption capacity (AC) and their elongated and angular shape. Irregular shape influences the workability of the concrete. Coating paste surrounding recycled aggregates is around 25% to 60% of the aggregates by volume. It is most notable that the finer the aggregate, the higher the percentage of paste content [2,3]. Excessive paste content due to the high AC of recycled aggregates will cause poor workability and large slump-loss of concrete [4,5]. Such poor quality further hinders the strength development of the resulting concrete. Research [6,7] has indicated that the addition of an extra 5% of cement may be needed to compensate for the strength-reduction. Furthermore, due to the inconsistency of the surface of recycled aggregates, the variation in concrete properties is larger than when using normal aggregates (NA) [7,8].

High Performance Concrete (HPC), as it is well known, can be designed to have the desired higher workability, higher mechanical properties and/or greater resistance to chemical

* Corresponding author.
E-mail address: brian.tu@msa.hinet.net (T.-Y. Tu).

0008-8846/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2005.11.022

attack than those of traditional concrete [9]. Many waste materials have been proven to be successfully utilized in the manufacturing of normal concrete (NC) and even HPC [10]. However, there have only been a few attempts to utilize recycled aggregates in the production of HPC due to the original defects of recycled aggregates [11]. Nevertheless, the utilization of recycled aggregates for HPC is still necessary, as HPC is becoming more and more widely used around the world. Furthermore, the utilization of recycled aggregates might at least lead the concrete industry to embrace the concept of sustainable development in the near future. Accordingly, this paper will examine the properties of HPC, which use recycled aggregates that have originated from demolished-construction wastes. As the properties of recycled aggregates are different from those of natural aggregates, the characteristics of recycled aggregates will be presented. The properties of both fresh and hardened concrete are illustrated and further analysis of the influence of recycled, coarse and fine aggregates on the properties of HPC is presented.

2. Research plan

2.1. Materials

ASTM C150 type I cement, ASTM C618 Class F fly ash, and ASTM C595 blast furnace slag powder with the finesse of 4000 cm^2/g, which are produced in local factories in Taiwan were used in this research. The mixing water was local tap water. Demolished-construction wastes, mostly generated during the so called 921 Chi-Chi earthquake of 1999, were processed and used as recycled, coarse aggregate. After the basic procedures of breaking and crushing, the poorly graded aggregate was sieved and remixed to meet the ASTM C33 standards. Two types of fine aggregates were used in this research; one was from demolished-construction wastes with processing procedures similar to the production of the recycled, coarse aggregate. Natural, fine aggregates from Mainland China were also used for comparative and analytical reasons. The basic properties and gradation of aggregates in this study are shown in Tables 1 and 2, respectively. A naphthalene lingo-sulfonate based ASTM C494 type G (HPC-1000) super plasticizer (SP) was used to obtain the required workability.

Table 1
Basic characteristics of applied aggregates

Physical properties	Recycled coarse aggregate	Recycled fine aggregate	Natural fine aggregate
Specific gravity (SSD)	2.48	2.34	2.58
Specific gravity (OD)	2.35	2.12	2.57
Absorption capacity (%)	5	10	1
D_{max} (in)	1/2	#4	#4
FM	6.35	2.74	2.78
Dry-loose density (kg/m^3)	1349	1353	1689
Soil content (%)	1.5	5.9	2.31
Soundness (%)	−20.8	–	–
Los Angeles abrasion test (%)	29.34	–	–
Brick content (%)	18	38	0
Ceramic content (%)	1.04	1	0

Table 2
Sieve analysis of recycled aggregates

Coarse aggregate				Fine aggregate			
Sieve no.	ASTM C33	Original (%)	Selected (%)	Sieve no.	ASTM C33	Original (%)	Selected (%)
3/4″	100	87.44	100	#4	95~100	99.37	97.5
1/2″	90~100	71.95	95	#8	80~100	82.39	90
3/8″	40~70	54.36	55	#16	50~85	57.92	70
#4	0~15	10.16	7.5	#30	25~60	42.29	42.5
#8	0~5	0	2.5	#50	10~30	27.3	20
#16	–	–	–	#100	2~10	18.79	6

2.2. Mixture proportion design

Ten concrete mixtures were prepared using the Densified Mixture Design Algorithm (DMDA) [12,13] and these mixtures were separated into two groups, DR and DN. Group DR designated both recycled, coarse and fine aggregates while Group DN designated only the recycled, coarse aggregates used; and, the fine aggregate used was natural sand. Three w/b ratios: 0.32; 0.36; and 0.40; with the same water content of 160 kg/m^3, were used in the mixture designed for each group. In addition, another two concrete specimens with a water content of 150 and 170 kg/m^3 were designed for Group DR and Group DN where the w/b was 0.32.

2.3. Procedures of the proposed mixture design

DMDA [12,13] was developed by Professor Hwang and has been successfully applied to many projects in Taiwan, including its use in the construction of Taipei 101, the world's tallest building [14,15]. The major difference from other mixture design algorithms is that instead of partial replacement of cement, DMDA incorporating fly ash is used to fill the void of aggregates and hence increase the density of the aggregate system. The purpose of such action is to reduce the cement paste content for design properties such as workability, strength, and durability. As a result, besides physically acting as a filler, fly ash acts chemically as a pozzolanic material.

The weight ratio α_{max} of blended fly ash and sand can be expressed as the Eq. (1):

$$\alpha_{max} = \max\alpha = \frac{W_F}{W_F + W_S} \tag{1}$$

where W_F and W_S = the weight of fly ash and sand, kilograms per cubic meter, respectively.

Then, the blended fly ash and sand mixture at a fixed ratio of α_{max} is used to fill the void within coarse aggregates. Using a similar filling process, the maximum dry, loose density of blended aggregates can be obtained from the plot of blended fly ash/sand mixture and coarse aggregate. The weight ratio β_{max} at the maximum dry, loose density can be expressed as the Eq. (2):

$$\beta_{max} = \max\beta = \frac{W_F + W_S}{W_F + W_S + W_A} \quad (2)$$

where W_A = the weight of coarse aggregate, kilograms per cubic meter.

At the point of maximum density, the aggregate structure of fly ash, sand and coarse aggregate is assumed to be completely packed using the hand-dry rodding method in accordance with the ASTM C29 standard. From this, the void (V_v) among aggregates can be calculated and the minimum cement paste (V_P) can be estimated as Eq. (3). When considering the V_P for real concrete production, it is necessary to multiply a coefficient (N) to account for a lubricated layer ($V_L = S \cdot t$) on the surface of the aggregate (S) in order to achieve the workability of concrete.

$$V_p = V_v + S \cdot t = N \cdot V_v = N\left(1 - \frac{W_i}{\gamma_i}\right) \quad (3)$$

where S = the surface area of aggregates, square meter; t = the thickness of lubricating paste on the surface of aggregate, micrometer; V_v = the smallest void among aggregates, cubic meter; W_i = the weight of aggregate, kilogram per cubic meter; and γ_i = the density of aggregate, kilogram per cubic meter.

Due to the difficulty in measuring $S \cdot t$, it is suggested for convenience's sake that various $N \cdot V_v$ coefficients be tried to obtain the required workability. Thus the w/b ratio is calculated as following:

$$w/b = \frac{W + SP}{C + W_F + W_{SL}} \quad (4)$$

where SP = super plasticizers, kilogram per cubic meter; C = cement content, kilogram per cubic meter; W_{SL} = blast furnace slag content, kilogram per cubic meter; and W_F = fly ash content, kilogram per cubic meter.

The amount of blast furnace slag in Eq. (4) is 5% of the weight of cement. The dosage of SP was determined through previous experience and the workability of the concrete from a trial batch. The result of each concrete mixture is shown in Table 3.

2.4. Test program

Due to the unusual characteristics of recycled aggregates, some tests such as specific gravity under saturated-surface-dried (SSD) and oven-dried (OD) conditions, the AC, the dry-loose density, soundness and wear resistance (Los Angeles Test) were conducted to evaluate the quality of these aggregates. The sieve analysis, the properties of fresh concrete and hardened concrete, including slump and the slump-flow initial and at 60 min, the compressive strength, concrete resistivity, ultrasonic velocity and the chloride penetration, were conducted according to the relevant ASTM standards. Properties were further analyzed in relation to the influence of recycled aggregates on the properties of HPC.

Table 3
Mixture proportions of concrete (kg/m^3)

Mix	Water	Cement	Coarse aggregate	Fine aggregate	Fly ash	Slag	SP
DR32160	160	326	825	668	157	17	18
DR36160	160	269	847	686	161	14	16
DR40160	160	224	864	700	164	12	14
DR32150	150	292	850	688	161	15	20
DR32170	170	360	801	649	152	19	16
DN32160	160	320	723	922	163	17	18
DN36160	160	264	742	946	167	14	16
DN40160	160	218	757	965	170	12	14
DN32150	150	286	744	949	167	15	20
DN32170	170	355	702	895	158	17	16

1. DR and DN stand for the mixture with recycled, fine and coarse aggregates and the mixture with natural, fine aggregate and recycled, coarse aggregate, respectively.
2. The two digits of the mixture after DR and DN designate the w/b ratio, the end 3 digits denote the water content.

3. Results

3.1. Characteristics of recycled aggregates

3.1.1. Specific gravity and the absorption capacity

Results (Table 1) show that the specific gravity of recycled aggregates is lighter than that of natural aggregates due to the existence of loose paste and bricks in demolished-construction wastes. As a result of the soil and brick content in recycled aggregates, high porosity is created in recycled aggregates and recycled aggregates coated with loose-bound mortar, additionally the AC of recycled coarse and fine aggregate rises to 5% and 10%, respectively, as compared to those of normal, coarse and fine aggregates which are about 1% and 2%, respectively. Such high AC will lead to greater water demand, the need for large dosages of SP to maintain the same workability and there will also be greater workability loss [4].

3.1.2. Gradation

Results, with regards to ASTM C33 standards, demonstrate that the gradation of recycled aggregates used on its own does not qualify for concrete use (Table 2). Accordingly, a remixed gradation of recycled aggregates was selected during this research.

3.1.3. Dry-loose density

As aforementioned, recycled aggregates have lower specific gravity than that of natural aggregates and consequently the dry-loose density of recycled aggregates is lighter than natural aggregates in the range of 1350 kg/m^3 (Table 1).

3.1.4. Soundness and wear resistance

The soundness of recycled aggregates reaches 20.8% on average in comparison to the 18% required by the ASTM C88 standard. The wear resistance of recycled aggregate is around

Table 4
Fresh properties of HPC

Set	Initial			1 h		
	Slump (mm)	Slump flow (mm)	Flow time (s)	Slump (mm)	Slump flow (mm)	Flow time (s)
DR32160	260	715	60	275	670	90
DR36160	255	675	50	230	450	60
DR40160	230	550	85	0	220	0
DR32150	250	650	80	225	570	90
DR32170	270	735	90	15	200	0
DN32160	250	620	90	250	635	85
DN36160	230	500	65	220	410	90
DN40160	230	540	50	0	200	0
DN32150	200	380	85	180	350	95
DN32170	260	660	90	260	620	120

29.3%, which is better than 50% of the standards, but it is still poorer than 20%±2% of normal crushed aggregate. The results are shown in Table 1.

3.2. Fresh properties of HPC with recycled aggregate

The initial slump and slump-flow of Group DR and Group DN specimens meet the HPC requirements [13], 230~270 and 500~700 mm, respectively. After 1 h, most Group DR and Group DN specimens still maintain high flowability, except for specimens with a high aggregate content (DR40160 and DN40160), a high cement content (DR32170) and a low water content (DN32150). The results are shown in Table 4. Generally, the recycled aggregates with high AC have only a slight influence on the workability of HPC specimens during the initial stages, but if the water content in the concrete matrix is insufficient to cover the large water demand it will lead to poor workability after 1 h. This indicates that the workability loss is much higher than that of normal aggregates.

3.3. Hardening properties of HPC with recycled aggregate

3.3.1. Compressive strength

As the water content is fixed, it is generally acknowledged the lower the w/b ratio, the higher the compressive strength (Fig. 1) [12,13]. On the other hand, at the same w/b ratio, the higher the water content, the better the compressive strength for the Group DR specimens (Fig. 2) [13]. As for the Group DN specimens, the one with a water content of 160 kg/m^3 indicated that the compressive strength is slightly higher than those with a water content of 150 and 170 kg/m^3, where the w/b ratio is fixed. Normally, concrete utilizing the DMDA design with a fixed w/b should indicate that the lower the water content the higher the compressive strength [12–15]. These different findings result from the utilization of recycled aggregates in Group DR and Group DN. Recycled aggregates need relatively high water content to compensate for high AC. Insufficient water content and poor hydration will reduce strength development (Fig. 2). According to the literature reviewed [13,16,17], excessive amount of paste leading to a weak interface-zone and low density might also generate poor compressive-strength development. Comparing various compressive strengths, mixes of Group DN are generally higher than those of Group DR with the same water content and w/b ratio at a given age. This indicates that it is necessary to blend the natural and recycled aggregates mixture together when manufacturing HPC [18]. Compared to normal HPC [12–15], a 20~30% reduction in compressive strength was found. However, as other properties are satisfied, it might suggest that it is necessary to slightly increase design compressive strength whenever recycled aggregates are applied in the manufacture HPC.

3.3.2. Concrete resistivity

As a general rule, the higher the concrete resistivity, the more difficult the diffusion of chemical matter within concrete

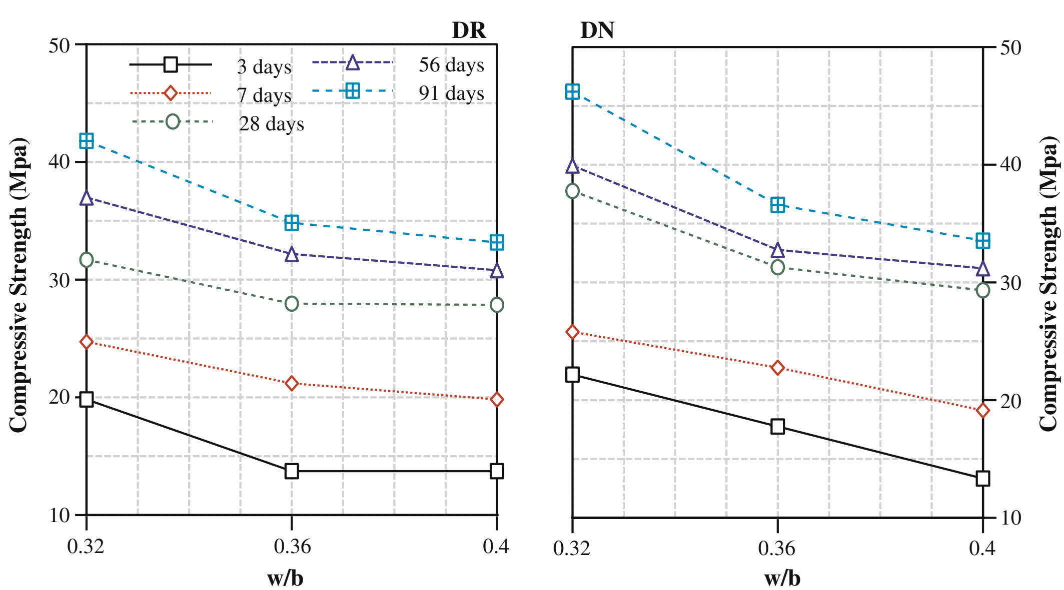

Fig. 1. The compressive strength of HPC versus the age and the w/b ratio (DMDA concrete with the same water content of 160 kg/m^3).

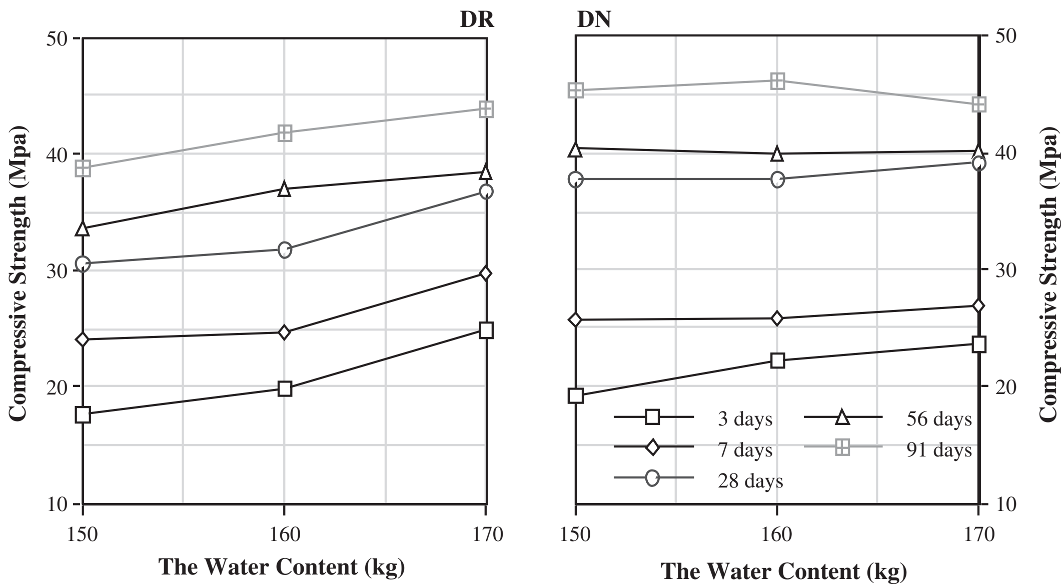

Fig. 2. The compressive strength of HPC versus the age and the water content (DMDA concrete with the same w/b of 0.32).

[13,17]. 20 kΩ-cm of resistivity is a reasonable measure for a durable HPC [19]. For Group DR and Group DN with the same water content, the lower the w/b ratio, the higher the concrete resistivity. For example, DR32160 reaches 50.1 kΩ-cm (Fig. 3), and DN32160 reaches 77.9 kΩ-cm at 91 days. On the other hand for the Group DN specimens with the same w/b ratio, but with variation in the water content, the lower the water content, the higher the concrete resistivity (Fig. 4). DN32150 can even reach 80.6 kΩ-cm at 91 days. This outcome reveals a similar trend to that of HPC designed by the DMDA using normal aggregates [12,13]. However, Group DR with a water content of 150 kg/m^3 does not have high concrete resistivity as expected at a given age. Since the water content is relatively low, insufficient water supply consequently influences the extent of the hydration reaction and is a possible cause for limiting the densification of the Group DR. At 28 days of age, the concrete resistivities for both Group DR and Group DN are still increasing, which is completely different from those specimens designed using the ACI-designed algorithm [13]. At 28 days, concrete resistivity of all specimens is higher than 20 kΩ-cm, therefore, the specimens might be considered to be durable concrete [19].

3.3.3. Ultrasonic Pulse Velocity (UPV)

With the same water content, DR32160 and DN32160 will achieve the best outcomes with regards to the UPV (Fig. 5). The trend with regards to the hardening properties of DMDA designed concrete is: the lower the w/b ratio, the higher the UPV [12,13]. On the other hand, with the same w/b

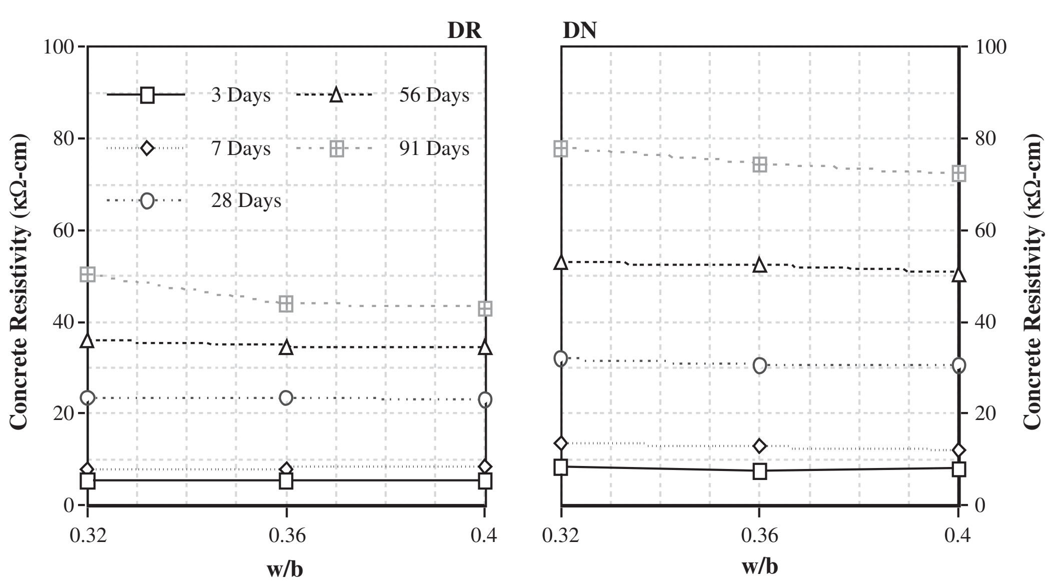

Fig. 3. The concrete resistivity of HPC versus the age and the w/b ratio (DMDA concrete with the same water content of 160 kg/m^3).

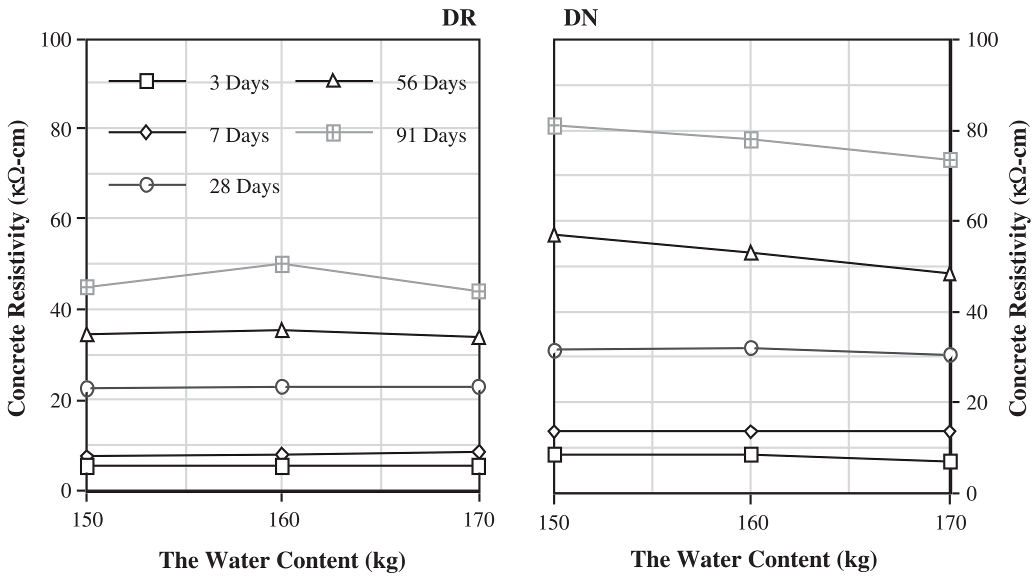

Fig. 4. The concrete resistivity of HPC versus the age and the water content (DMDA concrete with the same w/b of 0.32).

ratio, DR32160 and DN32150 show a better performance of the UPV for both Group DR and Group DN, respectively (Fig. 6). According to relevant DMDA research [12–15] at the same w/b ratio, the lower the water content, the higher the UPV. As DR32150 cannot have the best outcome in terms of UPV in DR group at a constant w/b ratio, it demonstrates the mix of natural and recycled aggregates can actually enhance the UPV of HPC designed using DMDA [18].

3.3.4. Chloride Penetration (CP)

In both Group DR and Group DN, which have the same water content, the lower the w/b ratio, the lower the CP value. Equally, at a fixed w/b ratio, the lower the water content, the lower the CP value for both Group DR and Group DN [12–15]. Under the same parameters, such as the same water content and w/b ratio, the CP value of the Group DN is better than that of the Group DR. That is, under the same conditions, specimens containing natural, fine aggregates perform better with regards to the CP value than those with recycled, fine aggregates. The addition of natural, fine aggregate will lower the residual-mortar content and enhance the durability of the concrete [19,20]. The CP values of all specimens at the age of 91 days are lower than 2000 C, a “low” level according to ASTM C1202 standards [13] (Fig. 7). Thus, HPC designed with DMDA and even applying

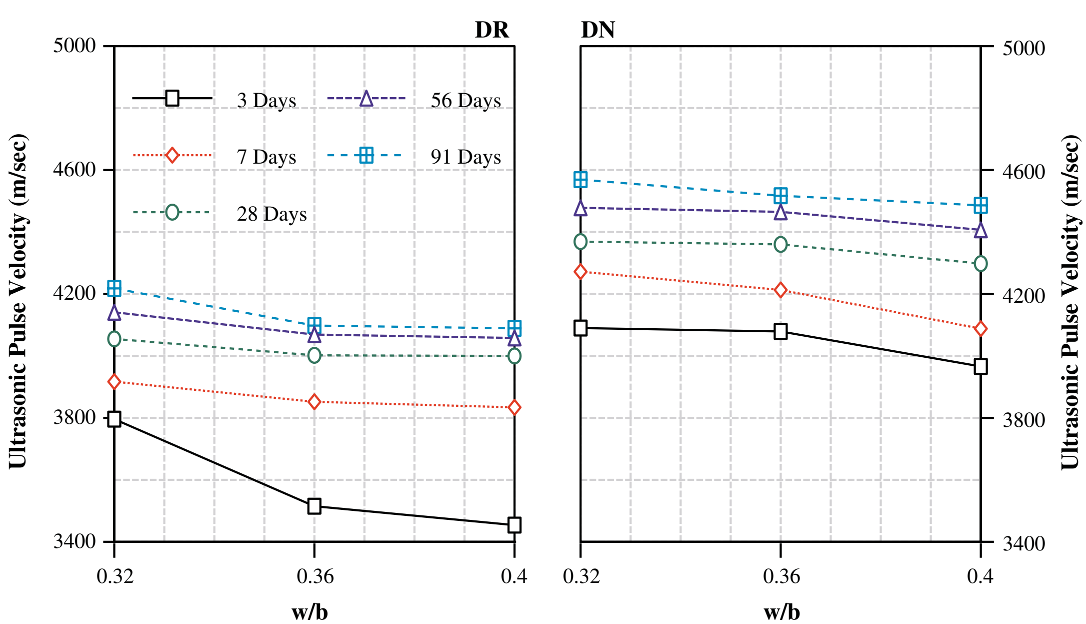

Fig. 5. The relationship between ultrasonic velocity and the age and w/b ratio (DMDA concrete with the same water content of 160 kg/m^3).

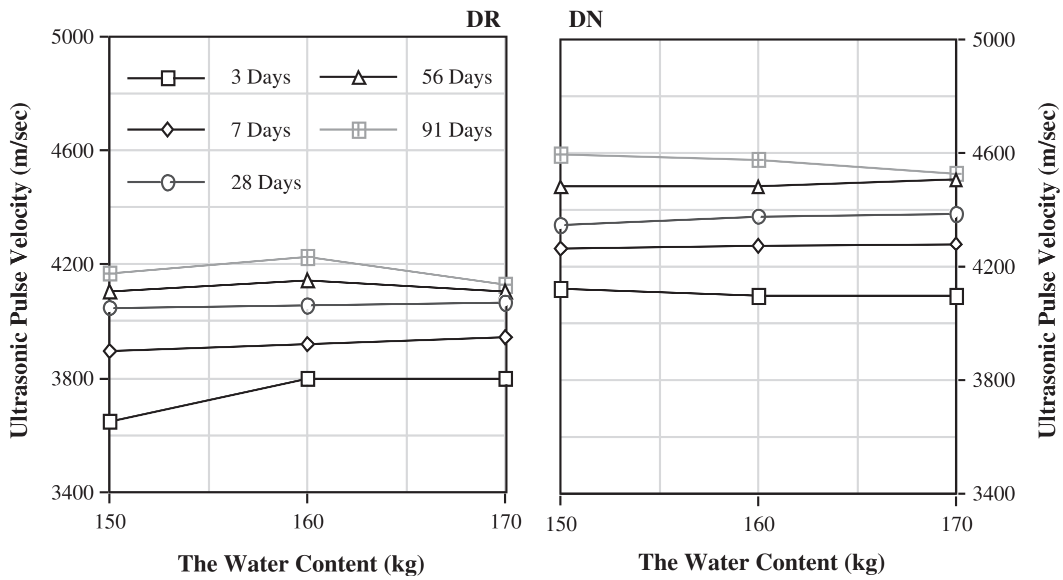

Fig. 6. The relationship between ultrasonic velocity and the age and the water content (DMDA concrete with the same w/b of 0.32).

recycled aggregates can resist factors that lead to severe degradation.

4. Conclusion

A thorough study of the effects of using recycled aggregate on the performance of HPC has been carried out, and the following provisional conclusions are given:

1. Basic characteristics, such as; specific gravity; the absorption capacity; gradation; dry-loose density; soundness and wear resistance of recycled aggregates are generally worse than those of natural aggregates due to the existence of residual mortar and impurities [20].
2. Mixes utilizing recycled aggregates have satisfied initial slump requirements with regards to HPC; however, they will have high slump-loss after 1 h due to the high AC of the recycled aggregate [4,5].
3. Whatever recycled aggregate is used to manufacture HPC, the trend of properties such as concrete resistivity, UPV and CP are very similar to those of normal HPC. However, a 20~30% reduction in compressive strength was found when compared to normal HPC [12–15]. This result is similar to others with recycled aggregate concrete [18,20]. Even so, when other physical properties, especially durability, satisfy HPC requirements, recycled aggregates could be used for HPC applications. Nevertheless, high design compressive strength is recommended.

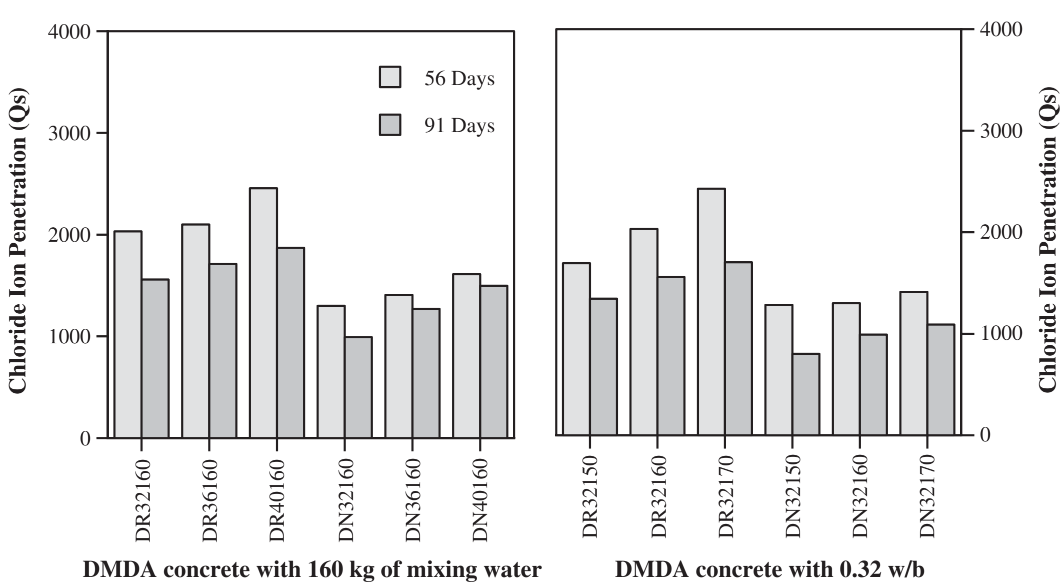

Fig. 7. The comparison of chloride penetration between DMDA specimens.

4. It is suggested not to utilize recycled aggregate for high, concrete strength applications due to long-term durability problems [21]. Durability can be further enhanced by the addition of natural, fine aggregates in the mixes [18]. More surprisingly, all mixes can have CP values lower than 2000 C at 91 days, and some mixes are even below 1000 C. According to ASTM C1202, these are very good results.

References

[1] WWF, the Living Planet Report, WWF, Taipei, 1998.
[2] T.C. Hansen, H. Narud, Strength of recycled concrete made from crushed concrete coarse aggregate, Concrete International, vol. 5, No 1, (1983), pp. 79–83, pp. 120–135.
[3] S. Hasaba, M. Kawamura, K. Toriik, K. Takemoto, Drying Shrinkage and Durability of the Concrete Made of Recycled Concrete Aggregate, The Japan Concrete Institute, vol. 3, 1981, pp. 55–60, additional information obtained from background report in Japanese.
[4] N. Su, B.L. Wang, Study on the engineering properties of recycled aggregate concrete and recovered aggregate from demolished concrete, Journal of the Chinese Institute of Civil and Hydraulic Engineering 12 (3) (2000) 435–444.
[5] T. Mukai, M. Kikuchi, H. Koizumi, Fundamental Study on Bond Properties Between Recycled Aggregate Concrete and Steel Bar, Cement Association of Japan, 32nd Review, 1978.
[6] A.D. Back, Recycle concrete as a source of aggregate, ACI Journal 74–22 (1977) 212–219.
[7] S. Frondistou-Yannas, Waste concrete as aggregate for new concrete, ACI J. Proc., vol. 74 (8), August 1977, pp. 373–376.
[8] C. DePauw, Fragmentation and recycling of reinforced concrete some research results, Chapter 5.3.2, in: P. Kreijger (Ed.), Adhesion Problems in the Recycling of Concrete, Nato Conference Series IV (Materials Science), Plenum Press, New York, NY, 1981, pp. 311–317.
[9] F.H. Wittmann, P. Schwesinger (Eds.), High Performance Concrete: Material Properties and Design, AEDIFICATIO Verlag GmbH, German, 1995.
[10] S. Chandra (Ed.), Waste Materials Used in Concrete Manufacturing, Noyes Publications, New Jersey, USA, 1997.
[11] W.Y. Tam, X.F. Gao, C.M. Tam, Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach, Cem. Concr. Res. 35 (2005) 1187–1194.
[12] C.L. Hwang, J.J. Lin, L.S. Lee, F.Y. Lin, Densified mixture design algorithm and early properties of high-performance concrete, Journal of the Chinese Institute of Civil and Hydraulic Engineering 8 (2) (1996) 217–219.
[13] C.L. Hwang, Properties and Behaviors of Concrete, Chan's Arch Books, Taipei, 1999.
[14] J.C. Chern, C.L. Hwang, D.H. Tsai, Research and development of high-performance concrete in Taiwan, Concrete International 17 (10) (1995) 1–76.
[15] L.S. Li, C.L. Hwang, A quality assurance system of SCC in Taiwan, The Proceedings of First North American Conference On the Design And Use of Consolidating Concrete, ACBM, 2002, pp. 275–280.
[16] P.K. Mehta, Concrete — Structure, Properties, and Materials, Prentice-Hall, N.J., USA, 1986.
[17] S. Mindess, J.F. Young, Concrete, Prentice-Hall, N.J., USA, 1981.
[18] A. Ajdukiewicz, A. Kliszczewicz, Influence of recycled aggregates on mechanical properties of HS/HPC, Cement and Concrete Composites 24 (2002) 269–279.
[19] N.R. Buenfeld, J.B. Newma, C.L. Page, The Resistivity of mortar immersed in sea-water, Cement and Concrete Research 16 (1986) 511–524.
[20] K.K. Sagoe-Crentsil, T. Brown, A.H. Taylor, Performance of concrete made with commercially produced coarse recycled concrete aggregate, Cement and Concrete Research 31 (2001) 707–712.
[21] R. Zaharieva, F. Buyle-Bodin, F. Skoczylas, E. Wirquin, Assessment of the surface permeation properties of recycled aggregate concrete, Cement and Concrete Composite 25 (2003) 223–232.