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Stress–Strain Curve and Carbonation Resistance of Recycled Aggregate Concrete after Using Different RCA Treatment Techniques

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Abstract: Five recycled coarse aggregate (RCA) treatment techniques including flow-through carbonation, pressurized carbonation, wet carbonation, nano silica (NS) pre-spraying and combined pressurized carbonation with NS pre-spraying, were utilized to improve the performance of recycled aggregate concrete (RAC). The characteristics of the stress–strain curves of RACs including peak stress, peak strain, elastic modulus, ultimate strain and toughness were evaluated after using the above RCA treatment techniques. A theoretical model for natural aggregate concrete was used to analyse the stress–strain curve of RAC. Additionally, the carbonation resistance of RAC after using different RCA treatment techniques were investigated. The results showed that the calculated stress–strain curve of RAC based on the theoretical model matched well with the experimental results. Among the three types of carbonation techniques, pressurized carbonation caused the highest improvement in peak stress and elastic modulus of RAC, followed by flow-through carbonation, the last was wet carbonation. The NS pre-spraying method contributed to even higher improvement in peak stress and elastic modulus of RAC than the pressurized carbonation method. The combined pressurized carbonation with NS pre-spraying exhibited the highest enhancement of RAC because both the RCA and the new interface transition zone (ITZ) were improved. The carbonation resistance of RAC was improved after using all the studied RCA treatment techniques.

Keywords: recycled aggregate concrete; nano silica; carbonation treatment; carbonation resistance; stress–strain curve

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Citation: Li, L.; Xuan, D.; Poon, C.S. Stress–Strain Curve and Carbonation Resistance of Recycled Aggregate Concrete after Using Different RCA Treatment Techniques. *Appl. Sci.* **2021**, *11*, 4283. https://doi.org/10.3390/app11094283

Academic Editor: Doo-Yeol Yoo

Received: 2 April 2021
Accepted: 27 April 2021
Published: 9 May 2021

1. Introduction

A huge amount of construction and demolition waste is being produced globally, which brings in many environmental problems and induces a heavy burden to the limited landfill capacity especially in populated areas such as Hong Kong. In the past decades, much research has been conducted to utilize waste concrete as recycled coarse aggregate (RCA) as partial or whole replacement of natural coarse aggregate (NCA) to produce recycled aggregate concrete (RAC). It can not only reduce the amount of waste concrete, but also decrease the consumption of the natural resources to produce NCA. Nevertheless, because of the inferior physical properties of RCA when compared to NCA, such as higher water absorption, higher porosity, lower density and the presence of initial cracks [1–4], the mechanical properties and durability of RAC are lower than that of natural aggregate concrete (NAC) [5–9]. As a result, the use of RAC is currently still limited, and most of the applications are in non-structural uses [10].

To broaden the application of RAC, many RCA treatment techniques have been proposed to enhance the performance of RAC in the past few decades. In general, there are three categories of RCA treatment techniques in terms of their enhancement mechanisms. The first type is to remove the old mortar that is attached on RCA by mechanical grinding [11,12], heat grinding [13,14], ultrasonic cleaning in water [15], soaking in acid solutions [16], etc. However, these techniques have obvious disadvantages such as high energy consumption, high CO_2 emission, large amount of waste fines produced and the increased chloride and sulfate contents [3]. The second type is to enhance the old mortar of RCA and the old interface transition zone (ITZ) with methods such as accelerated carbonation [17–20], microbial carbonate precipitation [21], pre-soaking in sodium silicate solution [22] or polyvinyl alcohol [23,24], etc. The third type is to enhance the new ITZ between RCA and new mortar and many surface treatment techniques have been proposed to realize this purpose such as coating RCA with cement slurry [25], pozzolan slurries [26], nano materials [27,28].

Among these RCA treatment techniques, accelerated carbonation has attracted much research interest. According to the review study by Liang et.al [29], four types of acceleration carbonation methods have been utilized to pretreat RCA, which includes standard carbonation [30], pressurized carbonation [17–19], flow-through CO2 curing (or flow-through carbonation) [31], and water-CO_2 cooperative curing (or wet carbonation) [32]. By using acceleration carbonation, CO_2 reacts with the hydration product of cement such as $Ca(OH)_2$ and C-S-H and un-hydrated cement clinkers to produce calcium carbonate and silica gel, which densifies the microstructures of RCA [29,33]. As a result, the physical properties of RCA and the performance of RAC could be improved. However, different carbonation treatment methods vary a lot in terms of efficiency and operation easiness. It is necessary to compare the efficiencies of different carbonation treatment methods.

The use of nano silica (NS) to pretreat RCA has also attracted many researchers' interests. Currently, the commonly used technique is by pro-soaking RCA in colloidal NS [27,28,34]. This technique not only improves the physical properties of RCA, but also enhances the new ITZ between RCA and new mortar. However, this technique may have low economic feasibility because it consumes a large amount of NS due to high water absorption of RCA. Recently, a new NS treatment method, namely pre-spraying NS on the surface of RCA, was proposed by the authors [35]. It consumes much less NS than using the NS pre-soaking method. Moreover, it causes better improvement in the performance of RAC than using the pre-soaking method. However, considering the high price of NS, it is necessary to compare the efficiency of the NS pre-spraying treatment with other RCA treatment techniques before using it in real applications.

As mentioned above, the carbonation treatments could enhance the physical properties of RCA while the NS pre-spraying could improve the properties of the new ITZ between RCA and the new mortar. As a result, the performance of RAC could be improved. However, it is not clear which treatment contributes to better. As known, stress–strain curve and carbonation resistance are very important properties for structural concrete. Therefore, the objective of this study is to compare the characteristics of stress–strain curve and carbonation resistance of RAC after using NS pre-spraying and three types of carbonation treatments, namely flow-through carbonation, pressurized carbonation and wet carbonation. Moreover, a combined method with pressurized carbonation and NS-spraying was first adopted in this study. Considering that pressurized carbonation could enhance RCA while the NS pre-spraying method mainly enhance the new ITZ of RAC, it is expected that the combined pressurized carbonation with NS pre-spraying may give rise to an overall better enhancement of RAC.

2. Materials and Experimental Program

2.1. Materials

The cement used was an ordinary Portland cement CEM I 52.5N. The fine aggregate was a river sand with a fineness modulus of 2.6. The RCA was produced in the laboratory by crushing a batch of waste concrete block collected from a construction site in Hong Kong. The RCA was then sieved into two fractions, namely 10–20 mm and 5–10 mm. Crushed granite with sizes of 10–20 mm and 5–10 mm were used as NCA. The water absorption and particle density of NCA and RCA are shown in Table 1. A commercial colloidal nano silica (NS) with an average size of 106 nm was used. The pH value was 9.5. The density was 1.206 kg/m^3. According to the X-ray fluorescence results, the contents of SiO_2 in the colloidal NS was 34.3%, the content of Na_2O was 0.2% and the rest was water.

Table 1. Water absorption and particle density of coarse aggregates.

Aggregate	Size (mm)	Water Absorption (%)	Particle Density (kg/m^3)
RCA5–10	5–10	6.72%	2229
RCA10–20	10–20	7.77%	2196
NCA5–10	5–10	0.69%	2634
NCA10–20	10–20	0.57%	2602

2.2. *Different RCA Treatment Techniques*

In this study, five RCA treatment techniques, which includes flow-through carbonation, pressurized carbonation, wet carbonation, NS pre-spraying, and the combined pressurized carbonation with NS pre-spraying, were adopted to enhance the performance of RAC. The details of them are given as follows.

2.2.1. Flow-Through Carbonation

Before the flow-through carbonation, RCA was pre-conditioned by storing in a chamber (T = 25 °C, RH = 50%) for 24 h, because this is the optimum moisture content for acceleration carbonation [29]. Next, RCA was spread out with one layer in a cylindrical chamber, in which pure CO_2 (>99% purity) was injected from one side and emitted from the other side. The flow rate of CO_2 was 1.0 L/min. After carbonation for 24 h at room temperature (25 °C), RCA was stored in a chamber (T = 25 °C, RH = 50%) for air-drying before using it for casting concrete.

2.2.2. Pressurized Carbonation

A carbonation chamber, which was introduced in our previous study [19], was used for the pressurized carbonation. Similar to the flow-through carbonation, RCA was also pre-conditioned by storing in a chamber (T = 25 °C, RH = 50%). Then, RCA was placed inside the carbonation device and CO_2 was injected. The pressure in the chamber was control at +1.0 Bar. The duration of the pressurized carbonation was 24 h. Finally, the treated RCA was air-dried in a chamber (T = 25 °C, RH = 50%) before preparing the concrete.

2.2.3. Wet Carbonation

A batch of RCA was placed in layers in porous baskets and soaked in tap water, and the water was stirred by a mechanical device at 200 rpm at 25 °C. Then, CO_2 was injected into the water by using a flow rate controller and a fine-bubble generating diffuser. The water to RCA ratio was controlled at 10:1, and the CO_2 gas flow rate was 0.2 L/min/(100 g RCA). The duration of wet carbonation was 6 h. Finally, RCA was removed from the container and air-dried in a chamber (T = 25 °C, RH = 50%) before preparing the concrete.

2.2.4. NS Pre-Spraying

The colloidal NS was pre-sprayed evenly on the surface of air-dried untreated RCA by a liquid spraying device when each batch of 5.0 kg RCA was rotated in an inclined mixer with a rotation speed of 10 rev/min. The amount of colloidal NS was control at 3% of RCA by mass. After that, the treated RCA was stored in a chamber (T = 25 °C, RH = 50%) for air-drying before casting the concrete.

2.2.5. Combined Pressurized Carbonation with NS Pre-Spraying

First, a batch of untreated RCA was carbonated by following the procedure of the pressurized carbonation technique above. Then, the colloidal NS was pre-sprayed on the surface of carbonated RCA with the same procedure of NS pre-spraying technique described above. Finally, the treated RCA was also air-dried in the chamber (T = 25 °C, RH = 50%) before preparing the concrete.

2.3. New Concrete Mix Proportions

Seven new concrete mixtures were prepared with the NCA, untreated RCA, and the RCA treated by five RCA treatment techniques above. The corresponding concrete mixtures were labeled as NAC, RAC-non, RAC-FC, RAC-PC, RAC-WC, RAC-NS and RAC-PCNS, respectively. The control mix proportion is given in Table 2. Considering the water absorption and moisture content of each type of coarse aggregate, extra amounts of water were added to maintain a consistent effective water to cement (W/C) ratio.

Table 2. Mix proportions of the control concrete (kg/m^3).

W/C Ratio	Water	Cement	Sand	Coarse Aggregate (5–10 mm)	Coarse Aggregate (10–20 mm)
0.60	195	325	752	282	846

2.4. Testing Methods

2.4.1. Measurement of Water Absorption and Particle Density of RCA

The water absorption and particle density of NCA and RCA were determined in accordance with BS 812-2. The particle density on an oven-dried basis was used in this study. To reduce the variation of sampling, the same batch of RCA was used to testing the water absorption and particle density before and after each type of RCA treatment technique.

2.4.2. Measurement of Density of Hardened Concrete

The density of hardened concrete was measured according to BS EN 12390-7. In this study, the mass of the hardened concrete in water-saturated state was measured. The volume of the hardened concrete was obtained by water displacement. The density of the hardened concrete was determined as the mass divided by the volume.

2.4.3. Measurement of Stress–Strain Curve of Concrete

Three concrete cylinders with the dimension of Φ100 mm × 200 mm were tested for each mixture. The stress–strain curve of concrete was determined according to the loading procedure prescribed in BS EN-12390. The loading rate was 0.6 MPa/s. The loading was terminated when the force was decreased to around 20% of the peak force after failure. The applied compressive force was measured by an internal force transducer in the testing machine. The displacement of each concrete specimen was measured by two linear variable differential transformers. The stress–strain curve of concrete could be obtained based on the force and average displacement.

2.4.4. Measurement of Carbonation Resistance of Concrete

The carbonation depth of concrete was determined according to an accelerating carbonation method described in BS EN 12390-12 using 100 mm× 100 mm × 100 mm cubes. First, the concrete cubes were preconditioned in the indoor laboratory environment for 14 days after curing in water for 28 days. Then, these samples were placed in a storage chamber, in which the CO_2 concentration was 3.5% by volume with the storage chamber was at a temperature of 20 °C and relative humidity of 57%, for periods of up to 28 days. After 7 days and 28 days of carbonation test, 2 concrete cubes were split in halves and the fractured surfaces were sprayed with a phenolphthalein indicator, which caused the uncarbonated zone to have pink color and uncarbonated zone the original concrete grey color. The edge of the pink color zone was marked and the distance to the sample surface at 4 points on each of the 4 faces was measured. The average value was calculated as the carbonation depth of each sample.

3. Results and Discussion

3.1. Water Absorption and Particle Density of RCA

Compared with that of the original RCA, the percentage of the decrease in water absorption of RCA and the increase in particle density of RCA after using different treatment techniques are shown in Figures 1 and 2, respectively. In the figures, FC, PC, WC, NS and PCNS represent flow-through carbonation, pressurized carbonation, wet carbonation, NS pre-spraying, and the combined pressurized carbonation with NS pre-spraying, respectively. It can be observed that the decrease in water absorption of the smaller size aggregate (RCA5–10) was larger than that the larger aggregate (RCA10–20). Among the three types of carbonation techniques, pressurized carbonation caused the largest reduction (14.4% for RCA5–10 and 11.9% for RCA10–20) in the water absorption value, followed by flow-through carbonation, and the last one was wet carbonation. After using the NS pre-spraying technique, the water absorption of RCA was only slightly decreased (3.6% for RCA5–10 and 2.8% for RCA10–20) which was even less than that of the wet carbonation. When using the combined pressurized carbonation with NS pre-spraying method, the water absorption exhibited the highest decrease (16.8% for RCA5–10 and 14.4% for RCA10–20) suggesting that these two methods can work effectively to enhance RCA. Generally, the increasing trend of the particle density corresponded to the decreasing trend of water absorption after the RCA was subjected to the different treatment methods. However, the magnitude of the increase in the particle density was much lower than that of the decrease in water absorption.

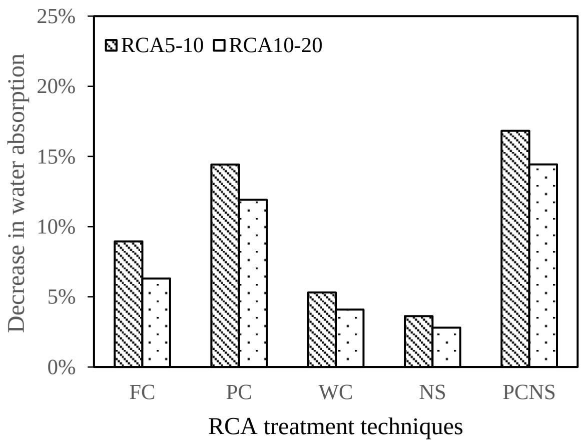


Figure 1. Decreasing rate of water absorption of RCA.

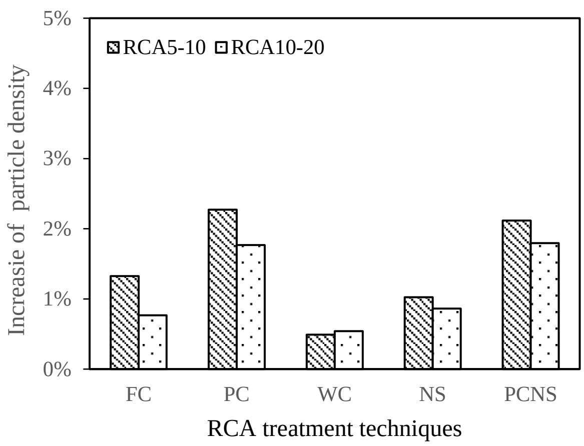
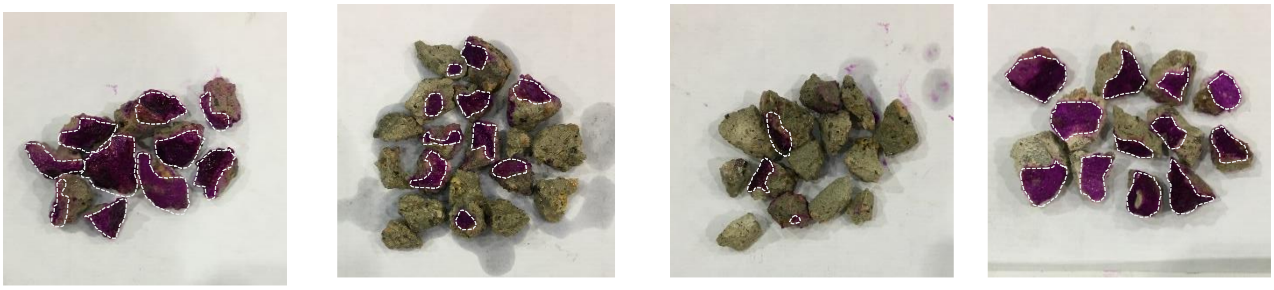


Figure 2. Increasing rate of particle density of RCA.

The images of the un-treated RCA and RCAs treated by three types of carbonation methods after spraying phenolphthalein solution are shown in Figure 3. A pink color (within dotted line in Figure 3) represents that the area was not carbonated. Some of untreated RCA was shown to have been carbonated on the surface because it was placed in air for a long time. However, the interior of the RCA was not carbonated. After using the pressurized carbonation technique, most of the interior of the RCA was carbonated. When using the flow-through carbonation, the carbonation degree was lower than using the pressurized carbonation. The carbonation depth of RCA was very small after subjecting to the wet carbonation. The results indicate that the water absorption and particle density of RCA are dependent on the carbonation degree of RCA.



(**a**) Untreated (**b**) Flow-through carbonation (**c**) Pressurized carbonation (**d**) Wet carbonation

Figure 3. Untreated and carbonated RCAs after spraying phenolphthalein solution.

3.2. Density of Hardened Concrete

The densities of the seven groups of new concrete prepared are shown in Figure 4. The results showed that the density of NAC was 5.8% higher than that of RAC prepared with the untreated RCA. That is because the density of NCA was higher than that of RCA. After using the treatments methods, the density of RAC was slightly increased. However, the magnitudes of the increase were very small (<1.0%).

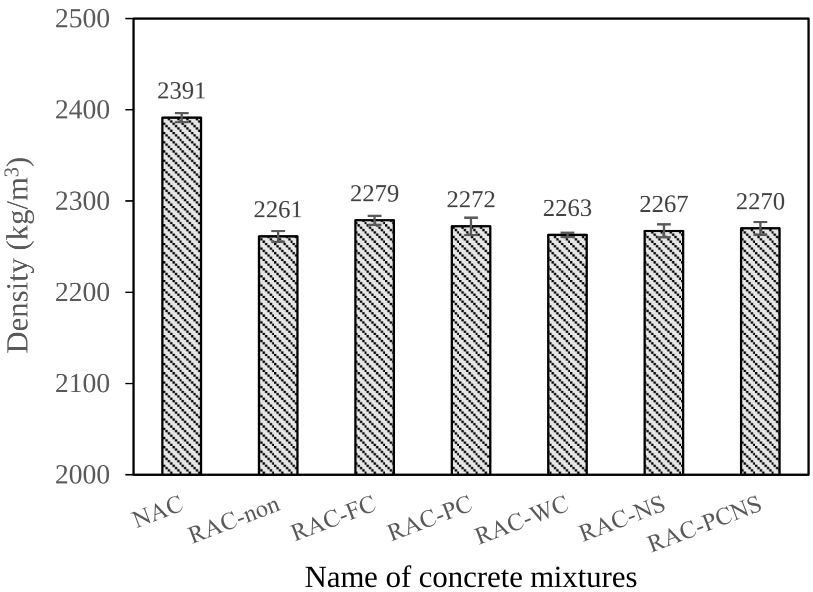


Figure 4. Densities of hardened concretes.

3.3. Stress–Strain Curve of Concrete

An example of stress–strain curve of concrete is shown in Figure 5. The peak stress is the maximum stress of the stress–strain curve. The peak strain is defined as the strain corresponding to the peak stress. The ultimate strain is defined as the strain corresponding to the stress at which 50% of the peak strain at the descending part of stress–strain curve is attained [19]. Toughness is an index to represent the energy absorption capacity of a material, which is often defined as the area under the stress–strain curve. In this study, toughness of the concrete is determined as the area under the stress–strain curve up to the peak stress of the concrete specimens [36]. The elastic modulus (E_c) is determined from the stress–strain curve using the following equation

$$E_c = \frac{\sigma_1 - \sigma_2}{\varepsilon_1 - \varepsilon_2} \quad (1)$$

where, σ_1 and σ_2 are the stresses corresponding to 5% and 1/3 of the peak stress, respectively; ε_1 and ε_2 are the strain values at the stress level σ_1 and σ_2, respectively.

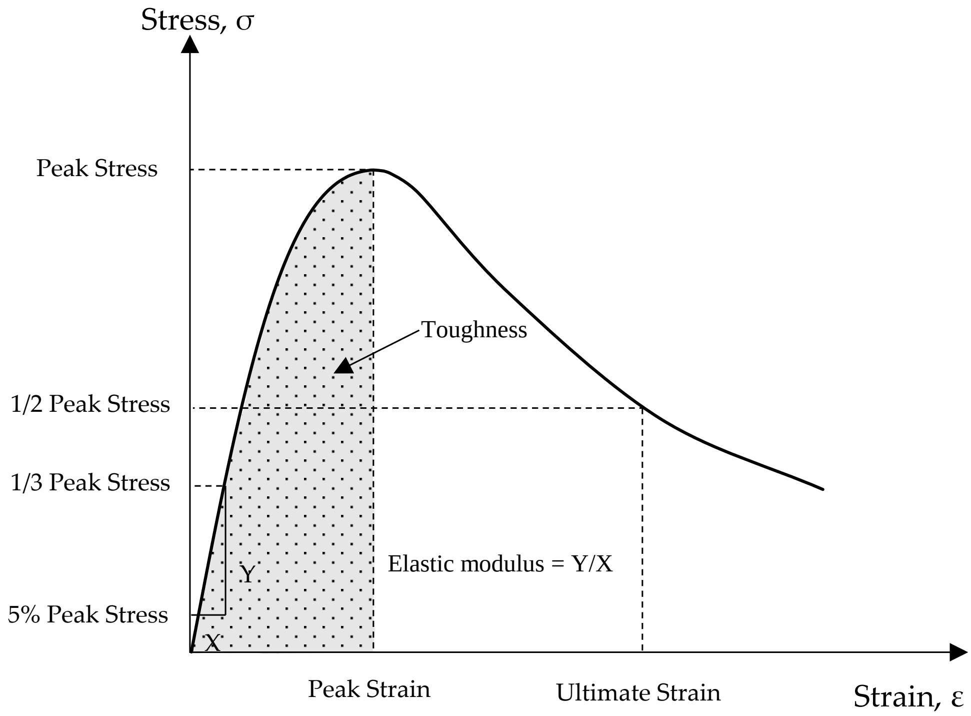


Figure 5. An example of stress–strain curve of concrete.

3.3.1. Peak Stress

The peak stresses of seven groups of concrete after subjecting to the compressive load test are shown in Figure 6. The peak stress of NAC was 44.7% higher than that of RAC-non. After using the RCA treatment techniques, the peak stresses of the RAC were increased. The increment by using the pressurized carbonation was higher than that of flow-through carbonation and wet carbonation. That is because when using the pressurized carbonation, the carbonation degree of RCA was higher than using other two carbonation techniques, leading to a better enhancement of RCA. The NS pre-spraying technique caused a slightly better improvement in peak stress than using the three types of carbonation techniques. That is because the ITZ between RCA and new mortar was enhanced after using NS pre-spraying, which may be more efficient to improve peak stress than the enhancement of RCA. When using the combined pressurized carbonation with NS pre-spraying technique, the peak stress exhibited the highest increase (17.1%) than the RAC-non because both the new ITZ and the RCA were enhanced. However, it was still significantly lower than that of NAC.

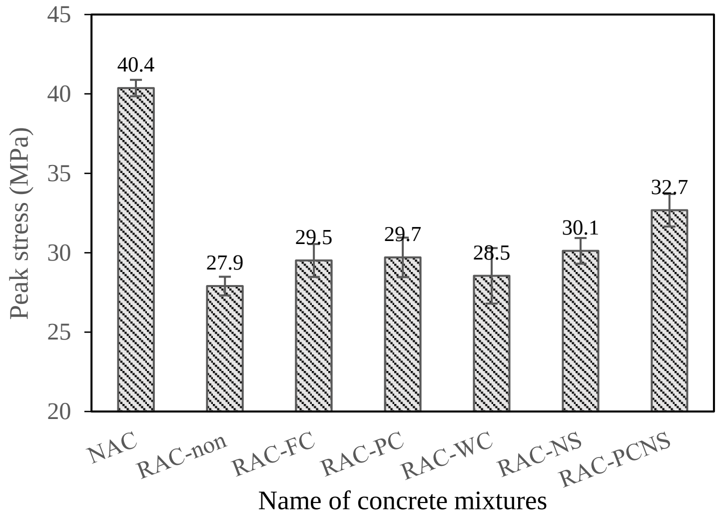


Figure 6. Peak stress of hardened concretes.

3.3.2. Elastic Modulus

The elastic modulus values of the studied concrete are shown in Figure 7. The elastic modulus of NAC was 30.3% higher than that of RAC-non. However, the elastic modulus of RAC was increased after using the treatment techniques. After using the three carbonation techniques, the increases were less than 3%. The NS pre-spraying technique induced a larger increase (7.6%). It indicates that the enhancement of the new ITZ might be more efficient in improving the elastic modulus of RAC than the enhancement of RCA. After using the combined pressurized carbonation and NS pre-spraying, the elastic modulus exhibited the highest increase (10.0%). However, the magnitude of increase in elastic modulus of RAC was much lower than that of the compressive strength, indicating that the influence of the carbonation treatments and NS pre-spraying treatments on elastic modulus of RAC was less obvious than that on compressive strength.

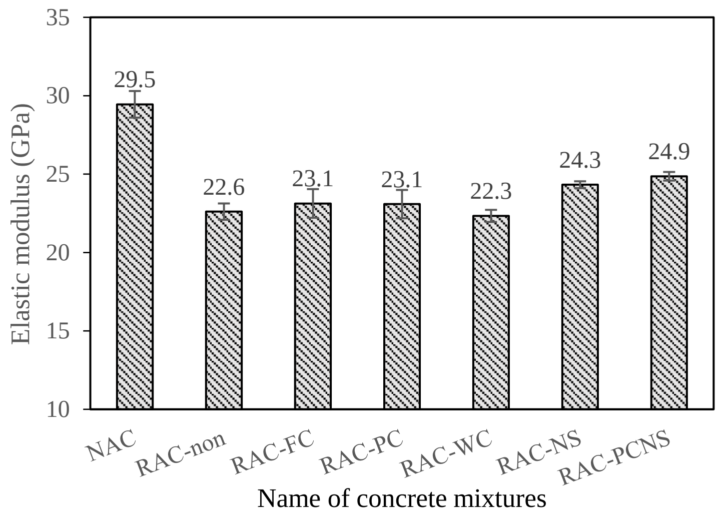


Figure 7. Elastic modulus of hardened concretes.

3.3.3. Peak Strain

The peak strains of the studied concrete are shown in Figure 8. It showed that the peak strain of NAC was slightly lower (1.2%) than that of RAC, and it did not show significantly changes after using the RCA treatment techniques although some variations were observed.

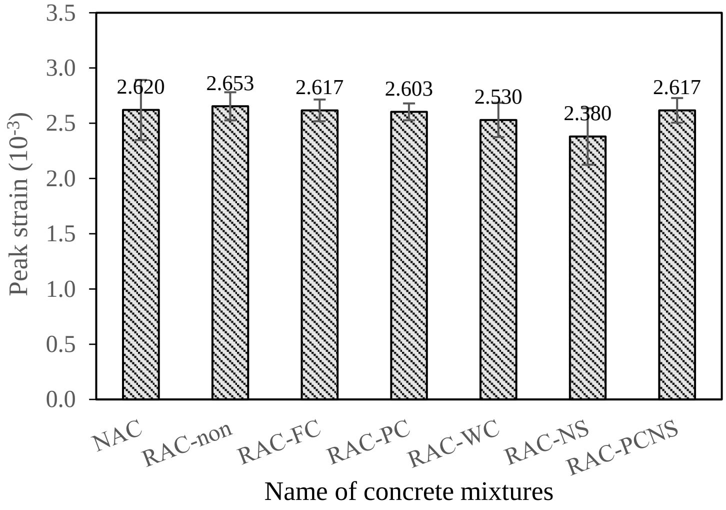


Figure 8. Peak strain of hardened concretes.

3.3.4. Ultimate Strain

The ultimate strain values of all the concrete specimens are shown in Figure 9. Similar to the peak strain, the ultimate strain of NAC was slightly lower (1.5%) than that of RAC-non. Meanwhile, after using these RCA treatment techniques, the ultimate strain of RAC were all reduced.

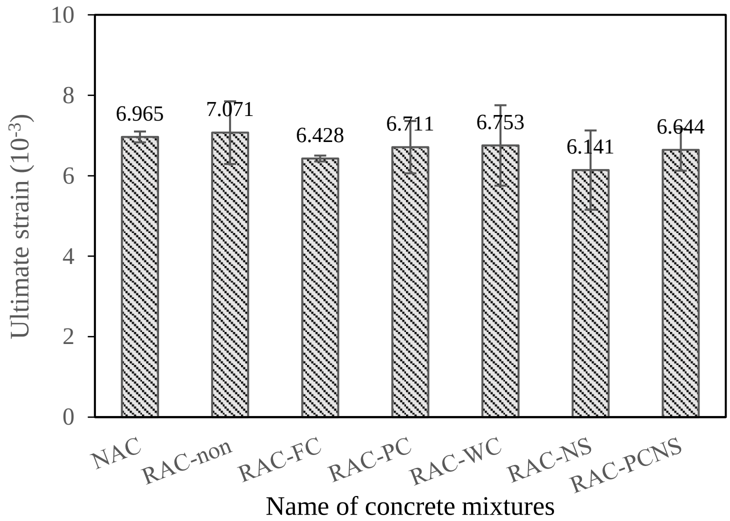


Figure 9. Ultimate strain of hardened concretes.

The ratio of ultimate strain to peak strain ($\varepsilon_{cu}/\varepsilon_{c,r}$) is a parameter used to describe the trend of the descending part of stress–strain curve. A higher $\varepsilon_{cu}/\varepsilon_{c,r}$ means that the stress decreases faster with the increase in strain at the descending part of stress–strain curve and the material is more brittle. The average $\varepsilon_{cu}/\varepsilon_{c,r}$ values of the NAC, RAC-non, RAC-FC, RAC-PC, RAC-WC, RAC-NS and RAC-PCNS were 2.52, 2.66, 2.46, 2.54, 2.66, 2.57, 2.54. After using the RCA treatment techniques, the $\varepsilon_{cu}/\varepsilon_{c,r}$ values were all reduced slightly, indicating that the stress decreased faster with the increase in strain at the descending part of stress–strain curve which also mean the concrete has become more brittle.

3.3.5. Toughness

The toughness values of all concrete specimens are shown in Figure 10. It shows that the toughness of NAC was 37.8% higher than that of RAC-non. After using the flow-through carbonation and pressurized carbonation, the toughness of RAC increased slightly (2.7% and 2.6%, respectively) because of the increased peak stress and elastic modulus. However, the toughness of RAC decreased slightly (5.7% and 5.6%, respectively) when using the wet carbonation and NS pre-spraying techniques. It may be related to the decreased peak strain. After using the combined pressurized carbonation with NS pre-spraying technique, the toughness of RAC showed much a larger increase, which was 13.1%.

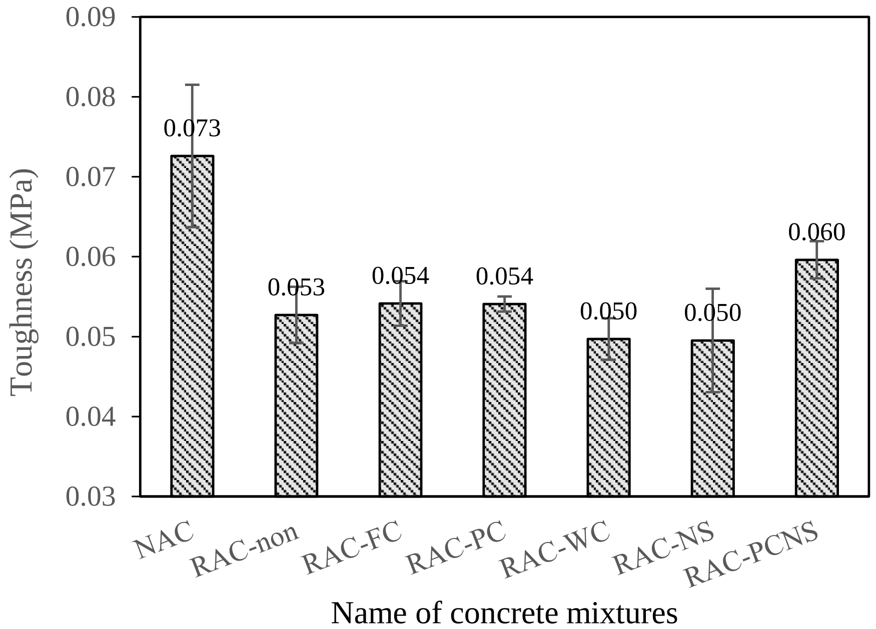


Figure 10. Toughness of hardened concretes.

3.3.6. Theoretical Model of Stress–Strain Curve

The theoretical model for stress–strain curve of NAC in the Chinese standard (GB50010-2010) was used to analyse the test results in this study. In the standard, the uni-axial compressive stress–strain curve is determined as

$$\sigma = (1 - d_c)E_c\varepsilon \quad (2)$$

$$d_c = \begin{cases} 1 - \frac{\rho_c n}{n-1+x^n} & x \leq 1 \\ 1 - \frac{\rho_c}{\alpha_c (x-1)^2 + x} & x > 1 \end{cases} \quad (3)$$

$$n = \frac{E_c \varepsilon_{c,r}}{E_c \varepsilon_{c,r} - f_{c,r}} \quad (4)$$

$$\rho_c = \frac{f_{c,r}}{E_c \varepsilon_{c,r}} \quad (5)$$

$$x = \frac{\varepsilon}{\varepsilon_{c,r}} \quad (6)$$

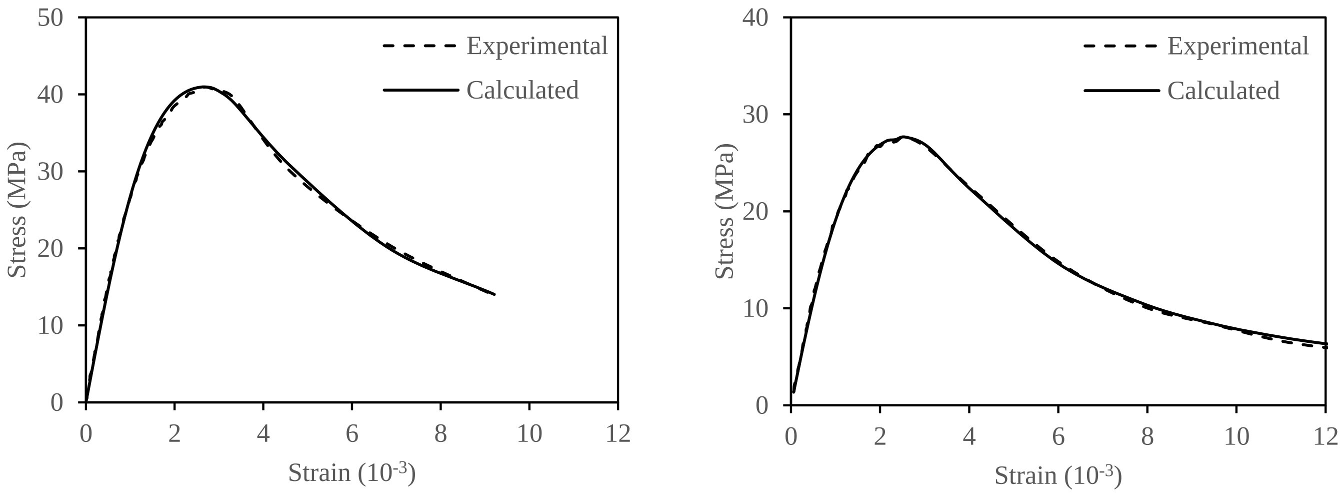
where, σ and ε are the stress and the strain of concrete, respectively, d_c is a parameter for damage evolution; $f_{c,r}$ is the representative value of compressive strength of concrete, it was taken as the peak stress in this study; $\varepsilon_{c,r}$ is peak strain of concrete; E_c is elastic modulus of concrete. α_c is a parameter for the descending part of stress–strain curve, which is related to the value of $\varepsilon_{cu}/\varepsilon_{c,r}$. Based on the Chinese standard GB50010-2010, α_c was taken as 0.74, 1.06, 1.36 and 1.65 when the value of $\varepsilon_{cu}/\varepsilon_{c,r}$ was 3.0, 2.6, 2.3 and 2.1, respectively. When the $\varepsilon_{cu}/\varepsilon_{c,r}$ was between the above values (3.0, 2.6, 2.3 and 2.1), the value of α_c was determined by linear interpolation method.

For each type of concrete, a typical experimental stress–strain curve was compared with the calculated one based on the above equations, as shown in Figure 11. It was observed that the experimental stress–strain curves of all concrete specimens matched well the calculated stress–strain curves. Therefore, it is suggested that the uni-axial compressive stress–strain curve of concrete given in the Chinese code (GB50010-2010) are also suitable to the RACs with untreated RCA and treated RCA by using the studied RCA treatment techniques.

3.4. Carbonation Resistance of Concrete

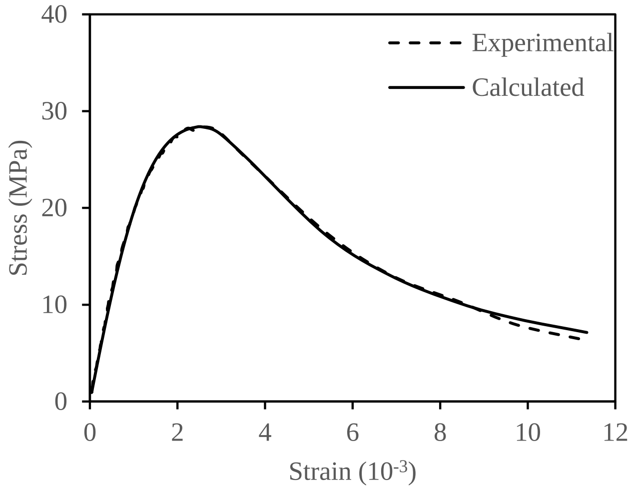
The carbonation depth of concrete is an indicator to assess its carbonation resistance. A lower carbonation depth means better carbonation resistance. The 7-day and 28-day carbonation depths of the seven groups of concrete are shown in Figure 12. The 7-day and 28-day carbonation depths of RAC-non were much higher than that of NAC. After using the flow-through carbonation, pressurized carbonation and combined pressurized carbonation with NS pre-spraying, the 7-day carbonation depths of the corresponding RACs were even larger than that of RAC-non. However, the 28-day carbonation depths of these RACs were lower than that of RAC-non. That is because the carbonated RCAs influenced the carbonation depth of RAC in two ways. On one hand, the carbonated RCA was more densified than that of non-treated RCA, which reduced the penetration rate of CO_2 and thus caused a reduction of carbonation depth. On the other hand, the carbonated RCA itself influenced the measurement of average carbonation depth, leading to an increase in carbonation depth of RAC. When the carbonation depth of RAC was small, the influence of carbonated RCA on the measurement carbonation depth was more significant. On the contrary, the influence of the carbonated RCA on the CO_2 penetration rate played a more important role when the carbonation depth became larger. It could be anticipated that when the carbonation resistant test duration was longer, the adverse effect of the carbonated RCA could be reduced.

In contrast, the 7-day and 28-day carbonation depths of RAC-WC were both reduced compared to RAC-non. That is because only the surface layer of the RCA was carbonated after using the wet carbonation. At the same time, more nano-$CaCO_3$ particles were formed on the surface of RCA, which would densify the new ITZ [37]. As a result, the penetration rate of CO_2 was reduced. This is similar to the NS pre-spraying method, in which the new ITZ could be significantly enhanced by the NS particles [35]. That is why the 7-day and 28-day carbonation depths of RAC-NS were similar to that of RAC-WC.

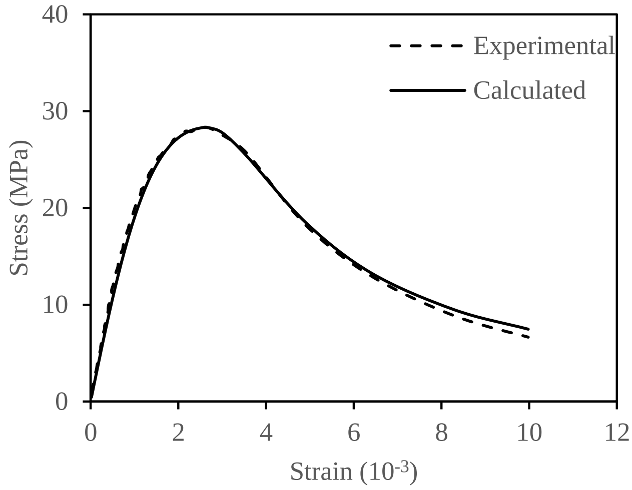


(**a**) NAC (**b**) RAC-non

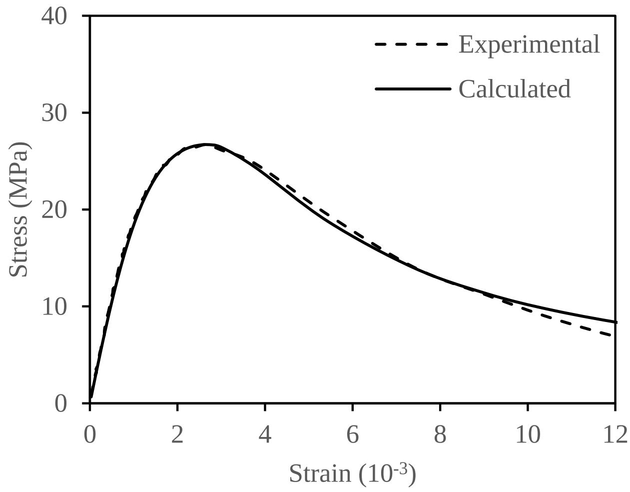
Figure 11. *Cont.*



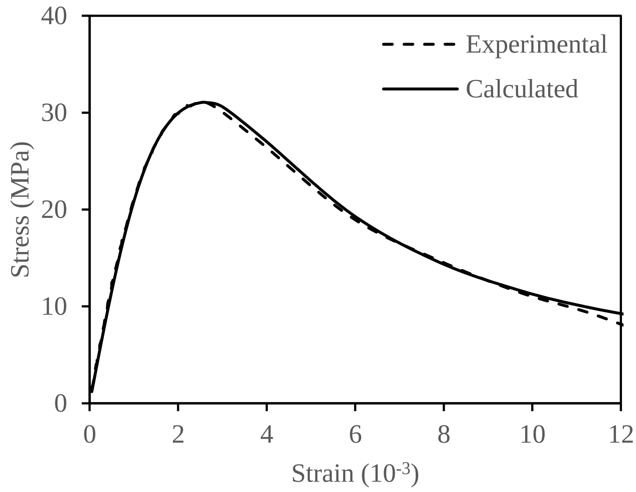
(**c**) RAC-FC



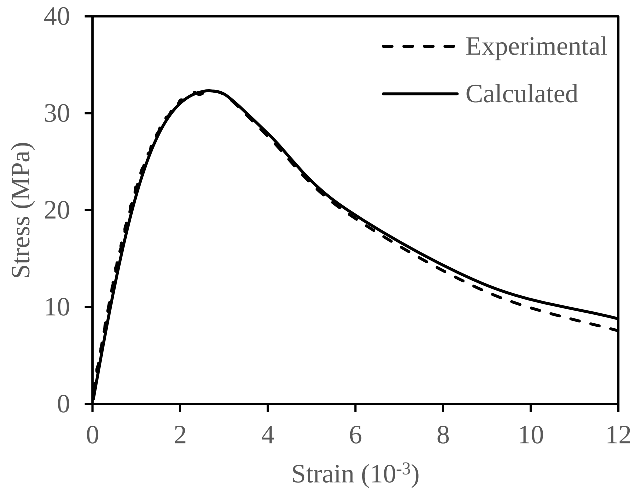
(**d**) RAC-PC



(**e**) RAC-WC



(**f**) RAC-NS



(**g**) RAC-PCNS

Figure 11. Experimental and calculated stress–strain curve.

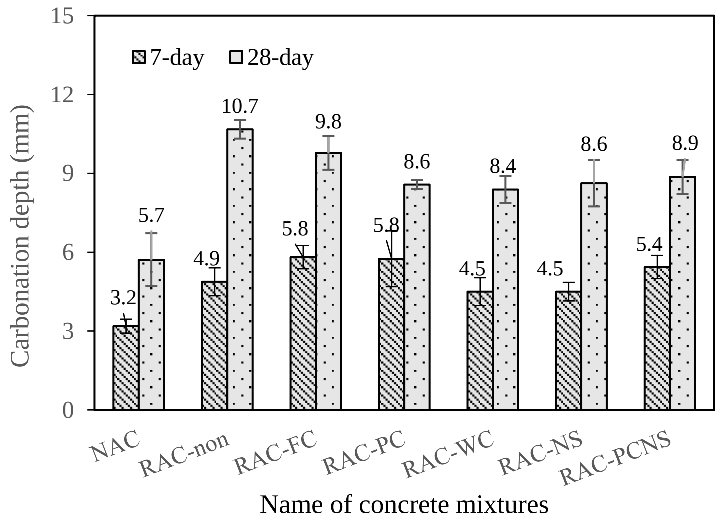


Figure 12. Carbonation depth of hardened concrete.

4. Conclusions

In this study, the stress–strain curves and carbonation resistance of recycled aggregate concrete (RAC) after using different recycled coarse aggregate (RCA) treatment techniques were investigated, namely flow-through carbonation, pressurized carbonation, wet carbonation, nano silica (NS) pre-spraying and combined pressurized carbonation with NS pre-spraying. Based on the testing results, the main findings can be summarized below.

(1) The theoretical model for stress–strain curve of natural aggregate concrete was also suitable to RAC after subjecting to the RCA treatment techniques. For all the studied RCA treatment techniques, the peak stress and elastic modulus of RAC were enhanced, but the peak strain did not show significantly changes while the ultimate strain exhibited some reduction.

(2) The 7-day carbonation depths of RAC after using flow-through carbonation, pressurized carbonation and combined pressurized carbonation with NS pre-spraying were larger than that of RAC using untreated RCA because of the negative effect the carbonated RCA. However, the 28-day carbonation depth of RAC was reduced after using all the studied RCA treatment techniques. In other words, the carbonation resistance of RAC could be enhanced by using these techniques.

(3) Comparing the efficiency of different RCA treatment techniques in enhancement of the peak stress and elastic modulus, the combined pressurized carbonation with NS pre-spraying was the best because both the RA and the new ITZ between RA and the new mortar was enhanced, followed by NS pre-spraying, pressurized carbonation and flow-through carbonation, and the worst was the wet carbonation because only the surface layer of RA was carbonated. The combined pressurized carbonation with NS pre-spraying can significantly improve the performance of RAC, which was better than the other four techniques. Thus, this technique has potential to be used in practical applications.

Author Contributions: Conceptualization, L.L., D.X. and C.S.P.; methodology, L.L., D.X. and C.S.P.; software, L.L.; validation, L.L.; formal analysis, L.L.; investigation, L.L.; resources, L.L. and C.S.P.; data curation, L.L.; writing—original draft preparation, L.L.; writing—review and editing, D.X. and C.S.P.; visualization, L.L.; supervision, D.X. and C.S.P.; project administration, D.X. and C.S.P.; funding acquisition, C.S.P. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Construction Industry Council (Hong Kong): CICR/03/19.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors wish to thank the Hong Kong Construction Industry Council (CIC) for financial support.

Conflicts of Interest: The authors declare no conflict of interest.

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