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Suzuki, Mariko

Inoue, Kazuya

Kawabata, Toshinori

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A Review of Data on Biodegradable Resin Concrete and Future Tasks

Mariko SUZUKI[1], Kazuya INOUE[1] and Toshinori KAWABATA[1]

[1] Graduate School of Agriculture Science, Kobe University, Kobe, Japan
msuzuki@peridot.kobe-u.ac.jp

Abstract. Biodegradable resin concrete is made of biodegradable resin and aggregate. The experiments on this new concrete started in 2012 and six papers were published. The strength degradation of biodegradable resin concrete was evaluated using the results of the three-point bending and compression tests, and the surface degradation was evaluated using the binarized photo data. The results showed that the decomposition of the biodegradable resin by microorganisms and the bond strength reduction between the biodegradable resin and aggregate by hydrolysis caused the degradation mechanism. Moreover, to estimate the fatigue life and clarify the strength-retention period of biodegradable resin concrete, the statistical deterioration prediction formulas were introduced using the Weibull distribution. This provided the appropriate estimates associated with the strength-retention period of biodegradable resin concrete. This paper summarizes the experimental results on biodegradable resin concrete and describes future tasks.

Keywords: biodegradable resin concrete; strength degradation; surface degradation; statistical deterioration prediction.

1 Introduction

Biodegradable resin has a short history and was discovered in the 1980s [1]. It has been used in many fields, from medical science to agriculture. In the field of medical science, biodegradable resin is used as a needle and suture thread [2]. In the field of agriculture, it is used as mulching materials, seedling pots, and nets for voluble stems [3], [4]. Previous studies elaborated on the mechanical properties of biodegradable resin [5], [6]. In the fields of engineering, the biodegradable resin is applied to some manufactures such as sandbags and ropes [7], [8] that are flexible materials. On the other hand, biodegradable resin concrete that is the target in this study, is a rigid material. Therefore, it is critical to clear its mechanical characteristics.
Temporary materials such as sheet piles made of steel or concrete are abandoned on-site after construction if they adversely affect the surrounding soil when they are extracted during construction work. Commonly used temporary materials abandoned on-site can cause various problems for future redevelopments such as a decline in land worth and industrial waste generation. To address these problems, biodegradable resin concrete prepared from biodegradable resin and aggregate was developed. Ex-

periments on this new concrete began in 2012, and six papers were published. The strength degradation of biodegradable resin concrete was evaluated by three-point bending and compression tests [9], [10]. The surface degradation was evaluated from binarized photo data [11]. Furthermore, to estimate the fatigue life and clarify, the strength-retention period of biodegradable resin concrete, statistical deterioration prediction formulas were introduced using the Weibull distribution [12]. This study summarizes the experimental results of biodegradable resin concrete and describes future tasks.

2 Outline of Experiments

2.1 Materials and mixture proportions of specimens

In this study, two types of biodegradable resin used as a bonding material were used for the biodegradable resin concrete, namely polybutylene succinate adipate (PBSA) and polylactic acid (PLA). PBSA was used because the biodegradable resin has a fast biodegradability [13]. The melting point of PBSA is 95 °C, and its melt flow rate (MFR) is 1–3 [14]. PLA, generated from corn, is a raw ingredient harvested in large quantities every year, and is an aliphatic polyester resin. The melting point of PLA is 170 °C, and its MFR is 17. The PBSA and PLA used in this study are shown in **Figs. 1** and **2**.

The specimens were prepared from biodegradable resin, fine sand, coarse sand, and calcium carbonate. The composition of the biodegradable resin concrete is listed in **Table 1**. Calcium carbonate was used to compensate for fine-grain fraction and it does not chemically react with the biodegradable resin.

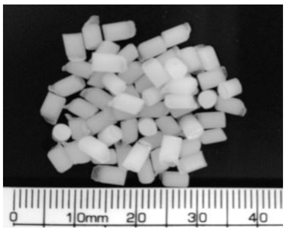

Fig. 1. PBSA

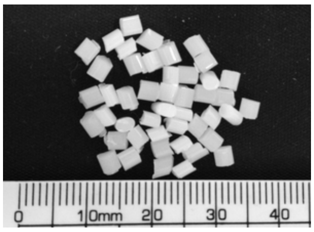

Fig. 2. PLA

Table 1. Mixture proportions of specimens

	ratio of mass (%)	
biodegradable resin	12	10
calcium carbonate	20	20
fine sand (fineness modulus: 1.09)	20	20
coarse sand (fineness modulus: 4.91)	48	50

2.2 Exposure conditions and tests method

Table 2 shows the adopted exposure conditions. The ligneous compost used Case A is composed of bark compost and peat moss, and full of microbes. Case C, aridity conditions, meant that specimens were placed in a box filled with silica gel. The specimens were placed in plastic boxes in each of the five exposure conditions. The insides of the boxes were maintained at 20 ºC. The exposure period was set to a maximum of two years.

Table 2. Exposure conditions

	ratio of mass (%)				
	A	B	C	D	E
washed sand	85	90	0	0	0
ligneous compost	5	0	0	0	0
silica sand	0	0	0	95, 90, 80	0
water	10	10	0	5, 10, 20	100

First, before the mechanical tests, the surface of the specimens exposed under Cases A, C, and E were observed with a digital microscope. The photos were taken every two weeks, and the shooting points were marked on the specimens so that photos could be taken at the same position. Pixels of 1024 × 1280 were captured and the central portions were cropped to 512 × 640. The pixels of 512 × 640 were binarized at a threshold of 128 after 256 shades of gray images were made [15]. The threshold of 128 was determined by trial and error to correctly discriminate between the aggregates and resin. This binarization was conducted for both PBSA specimens and PLA specimens at the same conditions. For further details of binarization, refer to the reference [11].

Three-point bending and compression tests were conducted to clarify the deterioration of the biodegradable resin concrete specimens. The sizes of the specimens were 40 mm × 40 mm × 160 mm for the bending test and 40 mm × 40 mm × 40 mm for the compression test.

3 Statistical Estimation of Degradation

It is critical to estimate the fatigue life and reveal the period for which the biodegradable resin concrete retains its strength. There are some prediction methods of degradation, namely physical and chemical formulas, statistical formulas, and turning numbers into an easily existing formula. This study used the Weibull distribution by considering the complexity of the degradation of the biodegradable resin concrete. It is one of the most widely used distributions in dependability analysis and flexibly applicable to fault curves. W. Weibull suggested the Weibull distribution in 1939 during his experiments of metallic fatigue life [16]. At that time, he concluded that the breakdown of brittle materials occurred due to independent flaws in materials. The 2 parameter Weibull probability distribution function is given by

$$F(t)=1\text{-}R(t)=1\text{-}\exp\left\{-\left(\frac{t}{\beta}\right)^{\alpha}\right\} \tag{1}$$

where $R(t)$ is the degree of confidence, t denotes time, α is the shape parameter, and β is the scale parameter.

4 Results and Discussion

4.1 Binarization

The micrographs of the specimen surface are shown in **Fig. 3**, and the proportions of white pixel count to total pixels after binarization are shown in **Fig. 4**. In Case C, the aridity condition and both the PBSA and PLA specimens remained almost the same as the initial state. In other words, the deterioration might not progress in an air-dried

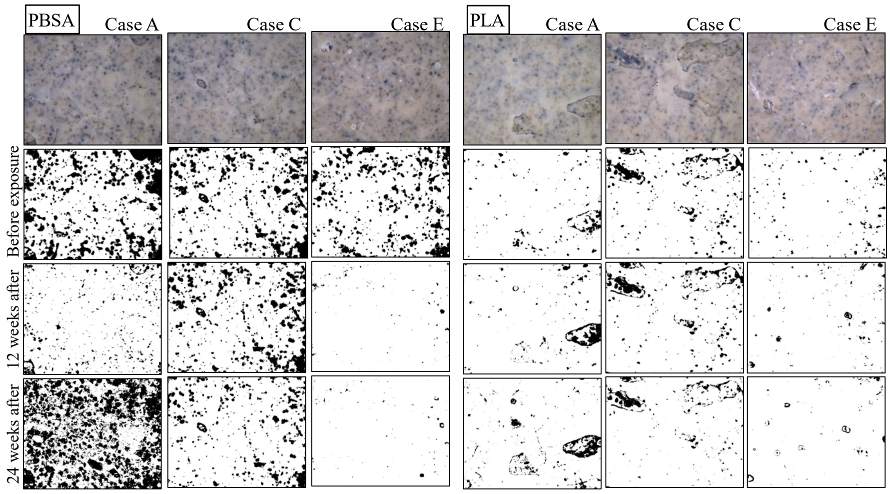

Fig. 3. Micrograph of the specimens' surface (PBSA and PLA)

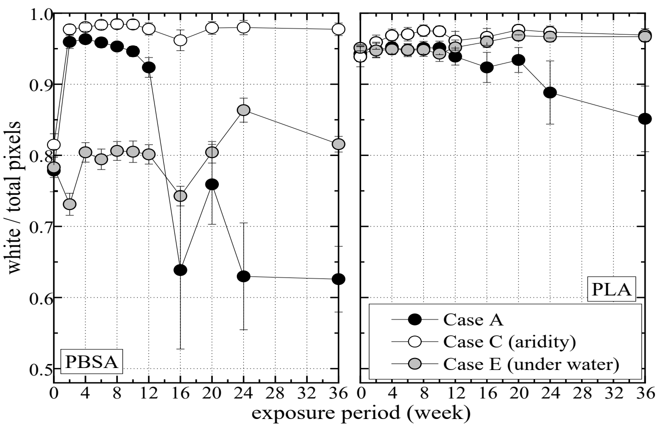

Fig. 4. Results of binarization (PBSA and PLA)

state. The specimen showing the most change is the PBSA specimen exposed in Case A. This specimen turned white after two weeks. After that, its surface slowly became black. This means aggregates outcrop owing to the degradation of the resin. However, no PLA specimens in Case A became black, indicating that no surface deterioration occurred. The PLA specimen surface is not deteriorated because PLA is hydrolyzed without the direct involvement of microorganisms [17]. The aqueous exposure of PBSA and PLA specimens (Case E) also did not become black. It is inferred from the observation of the specimen surface that microorganisms in soil decompose PBSA specimens.

4.2 Three-point bending test

The bending test results are shown in **Fig. 5**. A plot in the figure is the mean of five specimens. PBSA specimens were exposed for two years, and PLA specimens were exposed for one year. The bending tests were conducted every two months. The bending strength was reduced in all specimens with different resin ratios and soil patterns. The bending strength significantly decreases for six months after exposure. This strength reduction is not caused by microorganisms because the microbial degradation speed is slow. This significant strength reduction, therefore, could be because of the water affecting the bond strength between the biodegradable resin and aggregates. This is because the exfoliation of aggregates from the resin was confirmed at the broken-out section after the bending test.

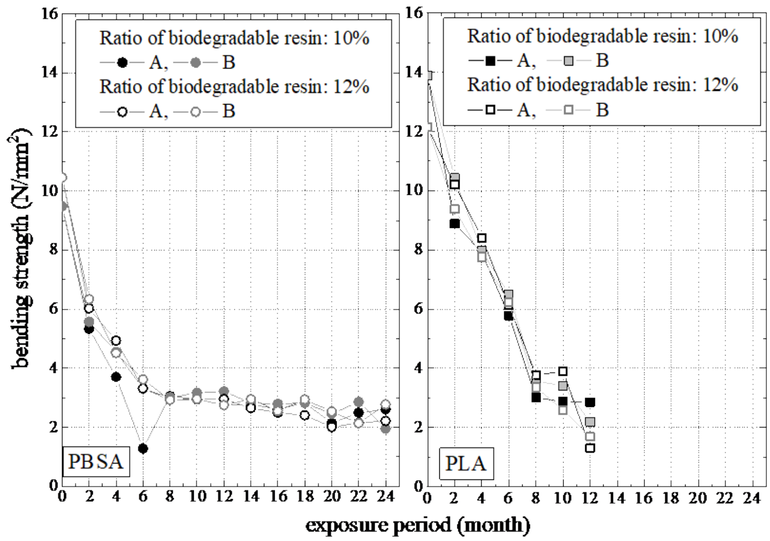

Fig. 5. Bending test results

Figure 6 shows the strength retention by a variation in water content. The remarkable strength reduction occurred for about six months. Therefore, the effect of water on the biodegradable resin concrete will occur a few months after exposure. Therefore, the

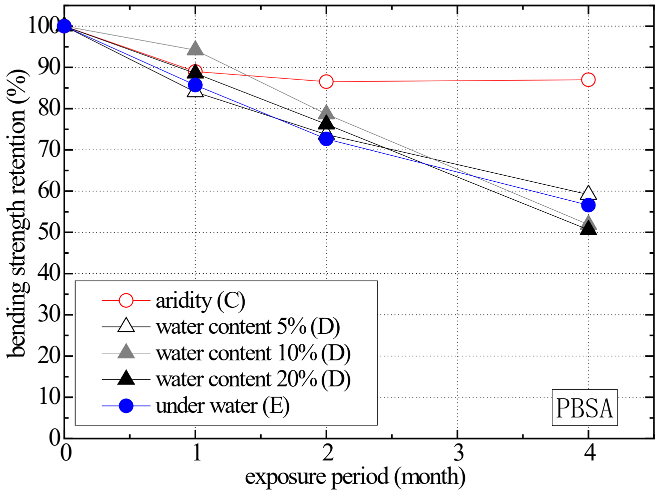

Fig. 6. Strength retention by a variation in water content

experiment was terminated to clarify the bending strength reduction by varying the water content for up to four months. The specimens of atmospheric curing (Case C) had little deterioration. The tendency of strength reduction from the Cases D and E was similar. From this result, this biodegradable resin concrete could be degraded if it is exposed to soil with a water content of more than 5%.

4.3 Compression test

Figure 7 shows the compression test results. The compressive strength reduction was observed in all the specimens with different resin types and soil patterns. Compressive

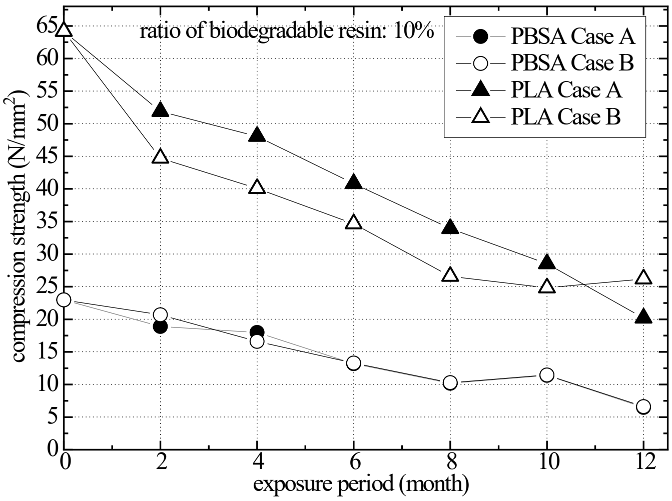

Fig. 7. Compression test results

strength stems from the strength of the aggregates. However, bending strength is the ascribable tensile strength of the resin. This is because the residual strength was kept higher than the bending residual strength. In other words, the inner part of the specimen retained its strength.

4.4 Estimation of degradation

The mean time to failure of PBSA and PLA are listed in **Figs. 8** and **9**. It shows how much time will be required to drop below each strength. It will be quite a long time before the strength of biodegradable resin concrete becomes zero from the present

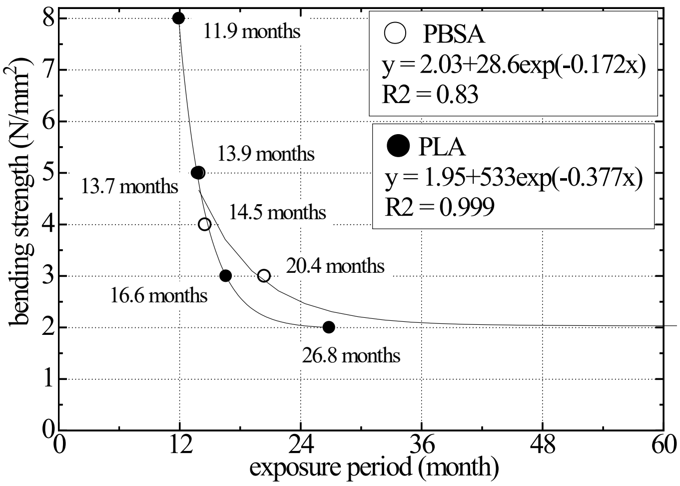

Fig. 8. Mean time to failure (MTTF) computed from the bending strength

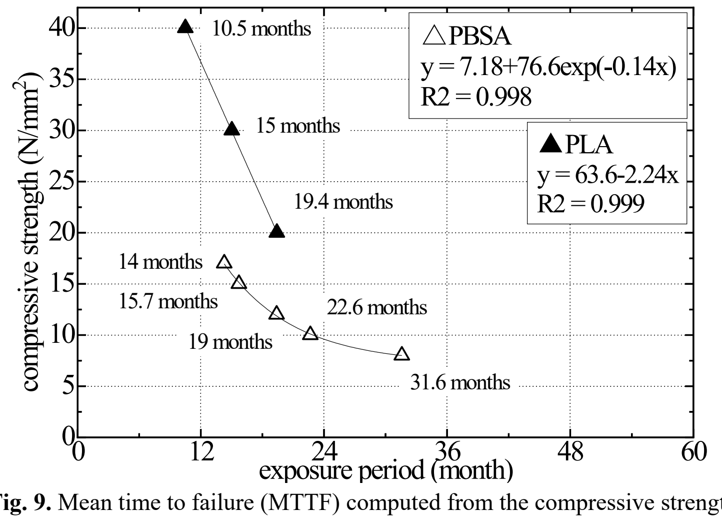

Fig. 9. Mean time to failure (MTTF) computed from the compressive strength

estimation model. This is not a surprising result because the biodegradation rate is slow after strength reduction using water. The biodegradable manufacture in previous studies by other researchers retained the shapes and strength even though the ropes were exposed for three years [18]. However, biodegradable resin concrete will not be harmful to land development because it is expected to reduce strength.

5 Future Tasks and Perspectives

The final goal of this study on biodegradable resin concrete is to achieve the practical use as the temporary construction materials such as sheet piles. The biodegradable resin concrete is the new construction material, and the biodegradable resin concrete was made through trial and error in this study. Biodegradable resin concrete requires further investigation. The biodegradable resin concrete is known to deteriorate owing to many factors such as microbial action, water, temperature, light, and ultraviolet rays. This study reported on microbial degradation and the action of water; therefore, the effects of other factors on the biodegradable resin concrete must be clarified. By establishing a deterioration control method, biodegradable resin concretes would be easy to use.

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