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The Effect of Aggregate Size and Resin Fraction on The Damping Capacity of Epoxy-Marble Composite

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Abstract

The production of material with high precission and high complexity has been rapidly increasing in several industrial sector. The high accuracy is difficult to achieve during manufacturing due to vibration factors that influenced the final product of material. In this study the relationship between particle size and percentage of marble aggregate with epoxy resin on damping capacity was studied systematically. The Composite materials were fabricated by using conventional casting technique with 10, 25, and 50% volume fraction of resin and two marble aggregate groups with 0.5-0.7 mm and 1.4-2.0 mm in particle size. The casting process was using multilayer pouring technologies to prevent void formation. 10% epoxy resin-fine marble aggregate has very good vibration result with 0.003 mm in displacement, 0.23 mm/s in velocity, and 0.2 m/s^2 in acceleration. The 10% epoxy resin-fine marble aggregate also has the best damping ratio among the composite due to the large specific area and porosity inside the marble material with value of 0.5%. The multilayer pour techniques for composite has been successfully adapted in this study to minimalize void/bubble formation inside and upperside of epoxy resin during the fabrication of composite. The secondary electron image of composite was observed that the marble aggregates and epoxy resin bonding are very good and no crack or void formation in the interface of the marble aggregate and epoxy resin.

INTRODUCTION

Nowadays, the production of material with high precission and high complexity such as ceramic, high alloy steel, non-ferrous, etc has been rapidly increasing in several industrial sector such as automotive, electronics, medical, and communication (Rajurkar et al., 2013; Yin et al., 2017). The high precission machine tools are developed to fulfill the requirement of the specific and complex material product (Ramana et al., 2021; Zhang et al., 2015). The high accuracy and precission is difficult to obtain during manufacturing. Several factors are influenced the final product of material such as cutting condition, machine tool, tool geometry, environmental condition, material properties, chip formation, tool wear, and vibration (Yin et al., 2017; Zhang et al., 2015; Zhang et al., 2015).

The material selection of base or structure for the construction in the machine plays an important role in vibration alleviation. The material must have high elastic modulus, high yield strength, good friction resistance, and high toughness due to the mechanical effect during the operation. It is also important to select material which has high vibration damping capacity to obtain the high precision product (Piratelli-Filho & Levy-Neto, 2010).

Currently, cast iron widely used in the high precission machine. However, the dimensional change during operation of precission machine due to the structure distortion is the main concern in the

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recent research (Piratelli-Filho & Levy-Neto, 2010). Particulate-filled polymer composite (PFPC), also known as polymer concrete, is new candidate material to alter the cast iron. Recent investigation have pointed out that PFPC based on ceramic can effectively minimize the vibration (Wang et al., 2014). The primary function of polymer is to transfer stress and binding aggregates together to provide any damages during the operation (Ribeiro et al., 2003).

Recently, it is essential to replace conventional ceramic and cast iron in composite due to the low cost and abundant waste materials without deteriorate the quality. Marble aggregates possesses the potential to improve damping capacity and reduce any dimensional change in the precision machine (Nayak & Satapathy, 2020). Several investigations have been made to assess the possibilities of using waste marble aggregates. Corinaldesi et al. have reported that the substitution of sand with 10% marble provided maximum compressive strength at the same level (Corinaldesi et al., 2010). The compressive and flexural strength increased significantly due to the addition of marble (Singh et al., 2017; Singh et al., 2016).

It is widely known that the partile size and the percentage of filler materials are critical parameters that significantly affect the properties of composite such as mechanical properties (Lian et al., 2011; Nambiar & Ramamurthy, 2008) and damping property (Panteliou et al., 2009). The previous study was reported that the mechanical properties of the composite is highly related to its components and the interface between resin and the aggregate/filler (Wang et al., 2014; Yin et al., 2015). Many studies focused on the effects of resin composition (Golestaneh et al., 2010; Haddad & Al Kobaisi, 2012) and mass content aggregate (Saribiyik, 2013), type of resin (Reis & Ferreira, 2006), and bonding between matrix and filler (Li et al., 2014) on the mechanical properties of composite. However, very limited study that focused on damping ratio of composite. In this work, the relationship between particle size and percentage of marble aggregate with epoxy resin was studied systematically. The behavior of epoxy-marble composite under vibration was investigated to find the optimum damping property of the composite.

MATERIALS AND METHODS

Materials

The composite material prepared in this study was mixture between epoxy and marble aggregate. The epoxy resin being used is Eposchon general purpose Bisphenol A Epychlorohydrin. The hardener which was used for the curing process of the resin, was provided by Eposchon type Polyaminoamide. The plasticizer which act as a diluent also provided by Eposchon type Epoxy Thinner EPD Z-8. The mixing ratio between resin and hardener is 1:1 as recommended by the manufacturer. The plasticizer was used to reduce the viscosity of the resin-hardener and the mixing ratio is 10% to epoxy.

The aggregates used in this study were marble particles obtained from local construction site in Padalarang, West Java, Indonesia.The density of the marble aggregate is 2.64 g/cm^3. The aggregates were sieved and classified into two different sizes. The coarse aggregate of marble has 1.4-2.0 mm of particle size and the fine one has 0.5-0.7 mm of particle size, respectively. The marble aggregate plays an important role to improve the damping capacity of composite materials.

Methods

Composite Fabrication

The Composite materials were fabricated by using conventional casting technique. The epoxy resin was prepared with three different volume fraction (10, 25, and 50%). After that, the hardener and the plasticizer were mixed together with epoxy resin for 5 minutes to ensure the homogeneity. The marble aggregate was poured into the stirring machine and was properly mixed with epoxy resin for 10 minutes.

In order to prevent any void and bubble inside and upper side of resin, the casting process was using multilayer pouring technologies (Yin, Zhang, Wang, Zhang, & Wang, 2018). As shown in Figure 1, several group of epoxy-marble with different number of layers were poured into the wooden mold (160 x 40 x 40 mm^3) at room temperature and were mixed together in the vibration table for 30 minutes. The curing process of epoxy-marble composite was performed in the room temperature for 24 hours.

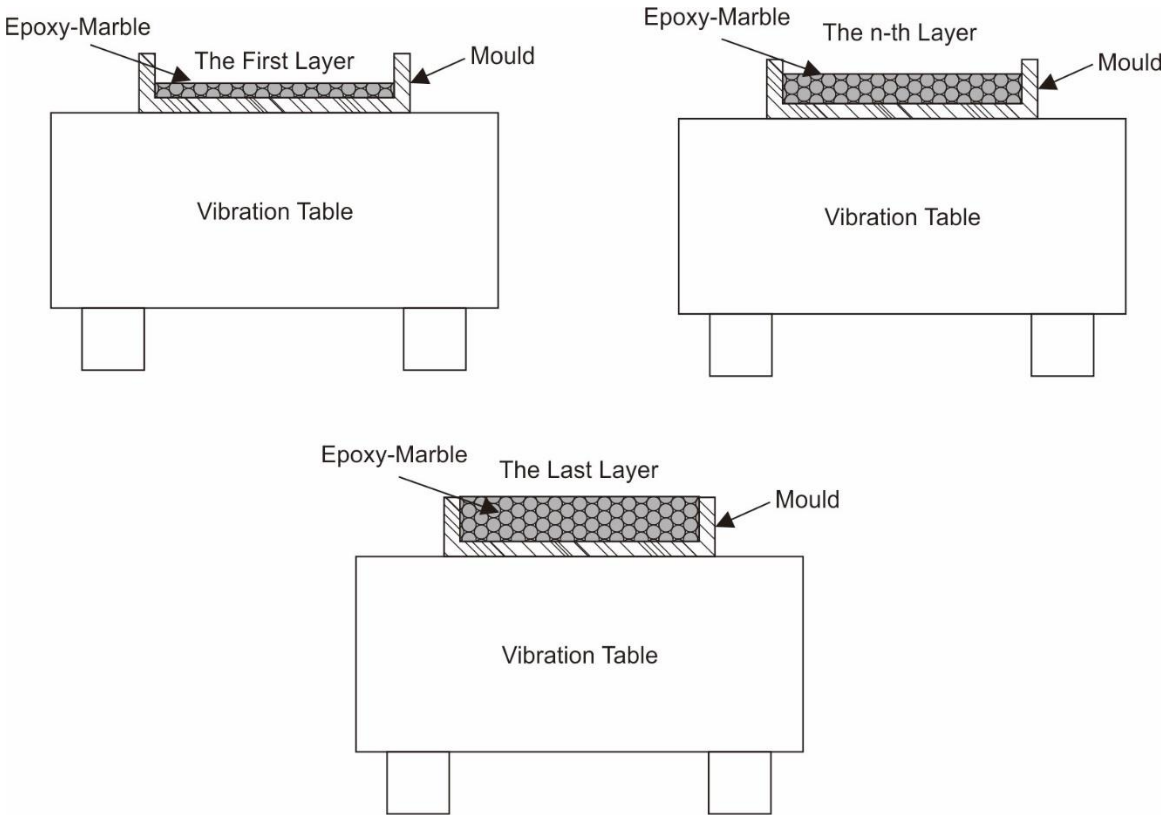

Figure 1. multilayer pouring technologies for composite fabrication.

Sample Characterization Techniques

The vibration damping test was performed in the Delta LF-350 machine with operation around 50 Hz. Each sample was placed center of the machine to avoid body movements and vibration noise in the measurement. The vibration of the machine was measured firstly by using Digital Vibrometer and was used as an initial vibration. The vibration was measured in the three different mode such as displacement, velocity, and amplitude. Meanwhile, the vibration test result of each sample was recorded and calculated to obtain the damping ratio.

The vibration calculation of the epoxy resin-marble composite was followed by below equation

$$d = \frac{v}{2\pi f} = \frac{a}{(2\pi f)^2} \quad (1)$$

$$v = d2\pi f = \frac{a}{2\pi f} \quad (2)$$

$$a = \frac{d}{(2\pi f)^2} = 2\pi f v \quad (3)$$

Note:

d = displacement amplitude (mm)

v = velocity amplitude (mm/s)

a = acceleration amplitude (m/s2)

f = frequency (Hz)

π = 3.14159265359

In order to study the morphology of the composite, each sample was cut into several pieces using circular saw machine with coolant (Mecatome OS 300, Presi 3B Poisat, France). After that, samples were grinding by using Grinder Polisher machine (MP-2B Grinder Polisher, Jinan Marxtest Technology Co.,Ltd, China). The morphology of each composite was observed by using optical microscope (Olympus QX 71, Olympus Corporation, Japan) and scanning electron microscope (Hitachi Su 3500, Hitachi High-Tech Group, Japan) using secondary electron technique.

RESULTS AND DISCUSSION

Each sample of epoxy-marble was subjected under the continuous vibration testing and the spectra of the frequencies that involve during the test was analyzed systematically. Figure 1 shows the displacement in time of one test with the machine and epoxy-marble composite. The blue and red signal are the signal result from the 1.4-2.0 mm marble aggregate with 10% epoxy resin and 0.5-0.7 mm marble aggregate with 10% epoxy resin. Meanwhile, the black signal was the initial signal

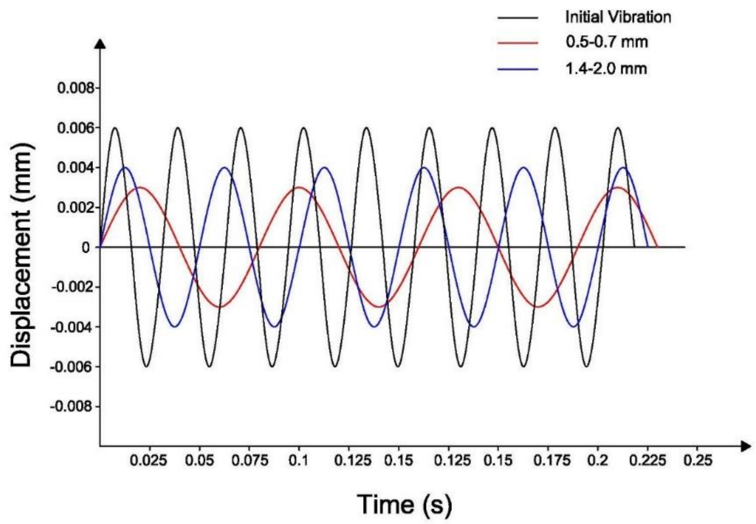

Figure 2. Displacement in time of the 10 % epoxy resin-fine marble composite (red curve) and 10% epoxy resin-coarse marble composite (blue line).

Table 1. Vibration test result

Aggregate Size (mm)	**Epoxy Resin (%)**	**Displacement (mm)**	**Velocity (mm/s)**	**Acceleration (m/s^2)**	**Damping Ratio**
	10	0.003	0.23	0.2	0.5
05-0.7	25	0.005	0.67	0.2	0.94
	50	0.008	0.83	0.4	1.17
	10	0.004	0.53	0.2	0.72
1.4-2.0	25	0.009	0.77	0.4	1.33
	50	0.007	0.77	0.5	1.33

from the machine itself. In the Figure 2, it can be observed that the machine vibration is higher than the composite vibration and the frequency spectrum of machine appear rapidly during the operation. Compare to the signal of the epoxy-marble composite, the composite with 10% epoxy resin and 1.4-2.0 mm marble aggregate has very limited displacement and frequency. It indicates that the 10% epoxy resin and 1.4-2.0 mm marble aggregate has minimize the vibration that occur during the machine operation. The other signal, red signal, has very small displacement compare to blue signal, which may indicate that 10% epoxy resin and 0.5-0.7 mm marble aggregate has performed better to prevent any vibration during the operating condition.

Table 1 shows the vibration test resuts of the epoxy resin-marble composite. The test was measured with three different mode; displacement, velocity, and acceleration. From the result the minimum displacent, velocity, and acceleration are from 10% epoxy resin and 0.5-0.7 mm marble aggregate with average value 0.003 mm, 0.23 mm/s, and 0.2 m/s^2. Meanwhile, within the same composition of epoxy resin, the vibration test of 10% epoxy resin and 1.4-2.0 mm marble aggregate is a little bit higher than 10% epoxy resin and 0.5-0.7 mm. 25% epoxy resin and 0.5-0.7 mm marble aggregate has average value of displacement, velocity, and acceleration of 0.005 mm, 0.67 mm/s, 0.2 m/s^2 and 25% epoxy resin and 1.4-2.0 mm marble aggregate has average value of displacement, velocity, and acceleration around 0.009 mm, 0.77 mm/s, 0.4 m/s^2, respectively. The last vibration test result is 0.008 mm, 0.83 mm/s, 0.4 m/s^2. from 50% epoxy resin with 0.5-0.7 mm marble aggregate and 50% epoxy resin with 1.4-2.0 mm marble aggregate with value of displacement, velocity, and acceleration around 0.007 mm, 0.77 mm/s, 0.5 m/s^2.

Figure 3 shows the damping ratio results of the epoxy resin-marble composite which measured by the Digital Vibrometer instrument. In that figure, the lowest damping ratio means that the material has high possibility to prevent vibration during the operation condition. As can be seen, the lowest

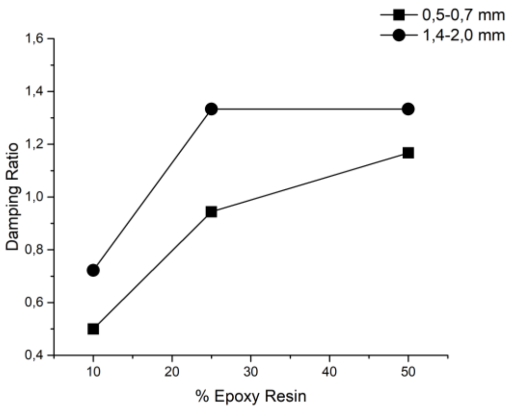

Figure 3. Damping ratio of epoxy resin-marble composite.

damping is from 10% epoxy resin and 0.5-0.7 mm marble aggregate with 0.5 % damping ratio and followed by 10% epoxy resin and 1.4-2.0 mm marble aggregate with 0.72 % damping ratio. Meanwhile, 25% epoxy resin and 0.5-0.7 mm marble aggregate has the damping ratio of 0.94% and 25% epoxy resin and 1.4-2.0 mm marble aggregate has damping ratio of 1.33%. For the 50 % epoxy resin and 0.5-0.7 mm marble aggregate has slightly better damping ratio compare to 50% epoxy resin and 1.4-2.0 mm marble aggregate with value value 1.17% and 1.33%. Eventhough, the displacement-velocity of 50% epoxy resin with 1.4-2.0 mm marble aggregate is better than 50% epoxy resin with 0.5-0.7 mm marble aggregate, the damping ratio of 50% epoxy resin-fine grain aggregate is better due to better acceleration of the material after subjected to the vibration machine.

Comparing the values of the different size of marble aggregate in the epoxy-marble composites, the optimum epoxy resin composite to prevent vibration is 10%. The higher volume fraction of epoxy-resin deteriorate the damping ratio of the composite. It means that the aggregate can distribute the stress and vibration that occur during the operating condition.

Another information that can be analyzed form the Figure 3 is the effect of aggregate size in the damping ratio results. The smaller the aggregate size, the damping ratio result will be small, respectively. It is well acknowledge that the ceramic material has porosity inside of it. So it means that the smaller aggregate size has more porosity inside and it useful to prevent any vibration during operation. The specific area of the small aggregate size will be higher than the bigger size aggregate. Because of that reason the smaller aggregate size will perform good stress distribution in the epoxy resin-marble composite.

Construction analysis was performed by taking optical microscope (OM) of the epoxy resin-marble composite. In the OM image, the interaction of marble aggregate with epoxy resin surface and their homogenization have been observed. The OM images of epoxy resin-marble aggregate are given in Figure 4. The interaction between marble aggregates with epoxy-resin was showed very clearly. In the 10% epoxy resin-marble composite as shown by Figure 4 (a) and 4 (b), the epoxy resin was formed as a bonding agent between marble aggregates. Figure 4 (c) and 4 (d) show a better bonding between epoxy resin-marble aggregates than bonding between epoxy resin-marble aggregates in Figure 4 (a) and 4 (b). As a result of the composite fabrication, it can be seen that the gravitation force between marble aggregates and epoxy resin was good enough in all volume fraction and marble aggregates.

Figure 5 shows the secondary electron image of epoxy-marble composite that examined by using SEM. with different magnification. In the Figure 5 (a), bubble or void inside the matrix composite can be shown very clearly. However, the formation of void can be minimalized by using the multilayer pouring technologies for composite fabrication. Another information that can be obtained is the bonding between epoxy resin and marble aggregate. As can be seen in the Figure 5 (b), the bonding between epoxy-resin and marble aggregate is well established in the composite.

CONCLUSION

Damping ratio of the epoxy resin-marble composite is highly related to the partile size and resin volume fraction. 10% epoxy resin-fine marble aggregate has very good vibration result with 0.003 mm in displacement, 0.23 mm/s in velocity, and 0.2 m/s^2 in acceleration. The 10% epoxy resin-fine marble aggregate also has the best damping ratio among the composite due to the large specific area and porosity inside the marble material with value of 0.5%. The multilayer pour techniques for composite has been successfully adapted in this study to minimalize void/bubble formation inside and upperside of epoxy resin during the fabrication of composite. The secondary electron image of composite was observed that the marble aggregates

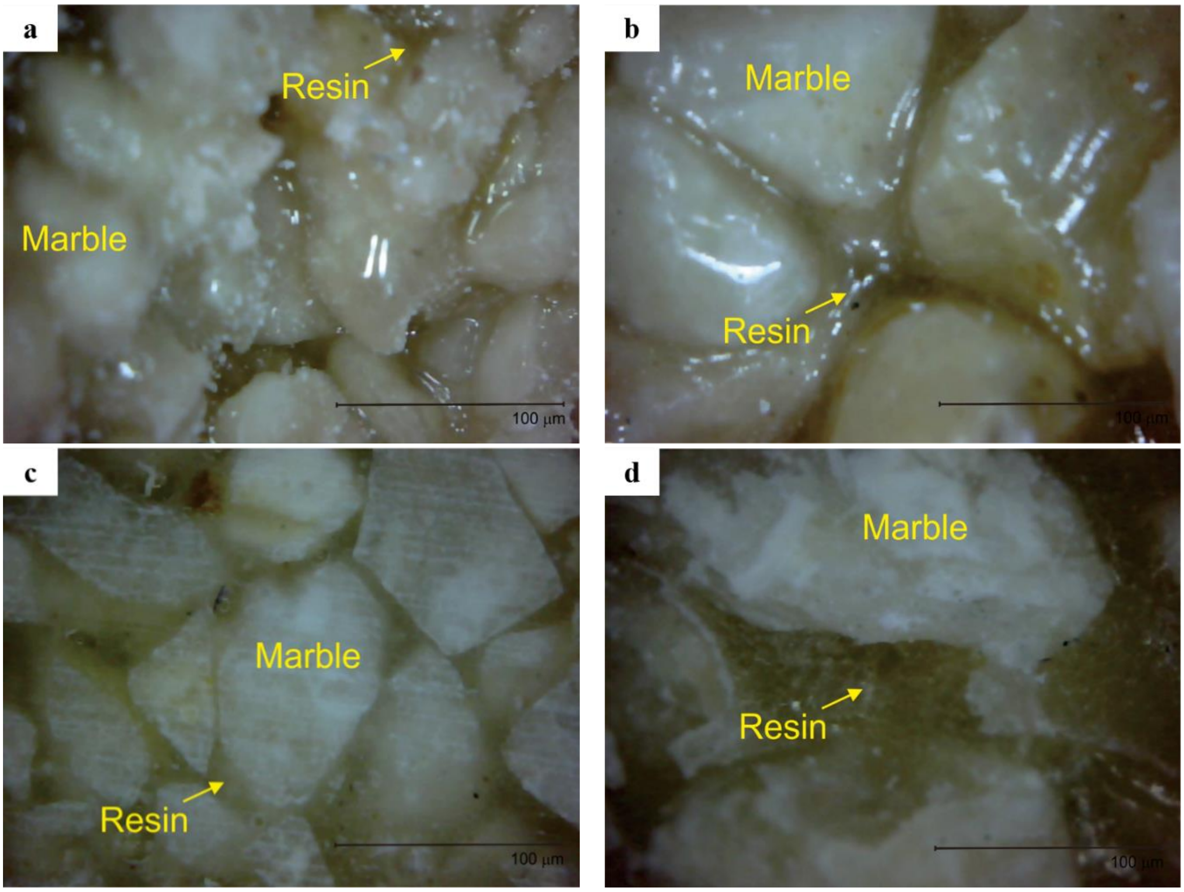

Figure 4. Optical micrograph of the (a) 10 % epoxy resin-fine marble composite, (b) 10% epoxy resin-coarse marble composite, (c) 25 % epoxy resin-fine marble composite, and (d) 25 % epoxy resin-coarse marble composite.

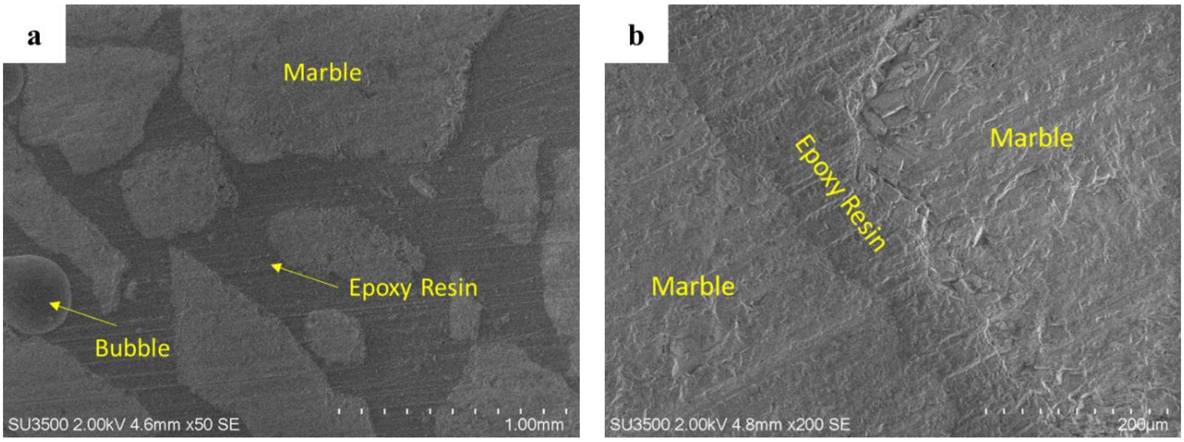

Figure 5. Secondary electron micrograph of the 25 % epoxy resin-fine marble composite with magnification (a) 50 times and (b) 200 times.

and epoxy resin bonding are very good and no crack or void formation in the interface of the marble aggregate and epoxy resin

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