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CONSOLIDATION EFFICIENCY OF IN-SITU APPLICATION CONSIDERING WEATHERING DEGREE FOR KOREAN SANDSTONE CULTURAL HERITAGE

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Abstract

The aim of this study is to examine the efficiency of ethyl silicate consolidants on sandstone according to the weathering state for an appropriate application to stone cultural heritage in Yeongyang area, Korea. There are many sandstone and conglomeratic sandstone cultural heritages in Yeongyang area, and they require conservation intervention due to granular disintegration and scaling of the stone surface. Hyeonri Three-storied Stone Pagoda made of typical sandstone of this area was investigated for the analyses of the material and deterioration. And both in-situ and laboratory applications of consolidants were conducted to the outcrop and quarried stones which showed same characteristics in rock types and weathering degree with the stone pagoda. As a result, Wacker OH 100 and Remmers 300 showed the highest consolidating effect, and Remmers 300 especially performed more strengthening effect for the loosen and granular-disintegrated surface of the Yeongyang sandstone.

Keywords: sandstone, Weathering Degree, Consolidation, In-situ Application, Ultrasonic Velocity

1. Introduction

Yeongyang area is known to be the representing district of sandstone distribution of Korean Peninsula and there are numerous national treasures and stone cultural heritages in the area. Many of these stone cultural heritages have gone through many restoration and preservation phases. However, most of the stone cultural heritages are exposed to the natural environments, as well as artificial damages and it leads to severe weathering of the exposed surfaces. Furthermore, the cement mortars and epoxy resin that were used for the restoration and conservation materials in the past are losing its functions, showing discoloration and cracking which is a problem in the conservation point of view.

In order to prevent any side effect as mentioned above, there is a necessity to analyze the characteristics of the resin used for foreign and domestic stone cultural heritage restoration, as well as the changes in the physical properties of the stones, before and after the treatment (Shin et al. 2004; Kim et al. 2009; Song et al. 2009a; 2009b; Lee et al. 2010). There is also a necessity for examining the mid-to-long term stability through regular monitoring and field application tests against natural weathering. However, scientific research on the characteristics of the conservation material has not been carried out considering the Korean climate and environment prior to its use. Now we are observing that the restoration and preservation materials are turning out to be playing a role in the persisting damage (Lee et al. 2010).

In this research, with having the material and weathering characteristics of the Korean sandstone cultural heritages in consideration, we have identified the damage status and the material characteristics of the stone pagodas and Buddha monuments dispersed in the area in order to choose the proper surface reinforcing material, as well as an effective treatment method. We chose the Hyeon-ri Three-storied stone pagoda (Treasure no. 610) as our test subject since it was severely damaged and showed common weathering phenomena of the sandstone works. Detailed material characterization and damage assessment were performed. We also searched and obtained an outcrop specimen that has the same material and similar weathering degree as the stone pagoda to perform indoor tests of the consolidants and in-situ application tests. With the test results, we have determined the suitable consolidant and method for the sandstones in the Yeongyang area.

2. Current status and research methods

At the Yeongyang study area, there are a total of 9 stone cultural heritages including 7 pieces of stone pagoda, 1 piece of stone Buddha monument, and 1 Buddhist flagpole supports. Most of these stone pagoda and Buddha monuments are composed of sandstone, and there is a development of cracks, joints and decomposition of the surfaces along the natural bedding planes. Also, the weathering degree is quite high, due to the exfoliation, peeling, and falling out of the sandstone. Especially, mechanical strength of the material of Three-storied stone pagoda of Hyeon-ri is dramatically decreasing due to natural weathering. Conservation intervention was performed in the past but further treatment is required due to deterioration and discoloration of the conservation materials.

We have selected the Three-storied stone pagoda of Hyeon-ri, which bears a wide range of weathering characteristics, as our research subject in order to establish a conservation remedy for the sandstone cultural heritages dispersed in the Yeongyang area. The comprehensive and quantitative examinations regarding the material characteristics and damage rate of the stone structures were performed. And we have collected sandstone samples in the Yeongyang area that are showing the same stone type and weathering degree as the stone pagoda. The samples were tested by laboratory experiments comparing the characteristics and performance before and after the consolidation. We also applied the consolidant to the outdoor outcrops and examined its stability.

3. Material characteristics and deterioration assessment

The material of the Three-storied stone pagoda of Hyeon-ri is composed of red to purple brown sandstone and conglomerate (Figure 1A). These stone types can be easily observed in the surrounding areas of the stone pagoda. These rocks are the main basement rocks of the Dogyedong Formation that is widely distributed in the Yeongyang area. The sandstone of the pagoda consists of anhedral quartz and feldspar, and clay matrix with irregular grain size and roundness distribution under polarized microscope (Figure 1B). The rock-forming minerals are loosely bonded together and the matrix is generally altered to clay minerals.

The conservation treatment for the stone pagoda was performed in 2005. However, since the stone pagoda was exposed to nature and climate changes, the weathering degree has rapidly changed higher due to the contraction-expansion of the minerals, chemical reactions and contamination. The most significant physical damage on the pagoda is granular disintegration and exfoliation. In the basement of the pagoda, a granular disintegration formed over the whole surface of the stone (Figure 1C), and exfoliation formed predominantly on the southern and eastern faces. In addition, the treatment materials applied in the past are deteriorated and discolored, and damaging aesthetic values of the pagoda (Figure 1D).

Figure 1. (A) Lithological characteristics and damage aspects of Three-storied stone pagoda in Hyeonri, reddish to purple brown sandstone and conglomeratic sandstone

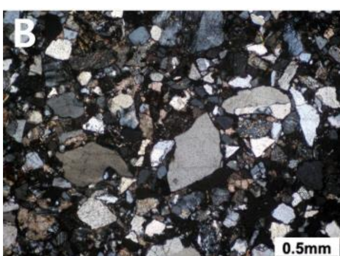

Figure 1. (B) Polarizing microscopic images showing heterogeneous roundness and grading of quartz

Figure 1. (C) Granular disintegration of the basement stone

Figure 1. (D) Discoloration of the conservation material

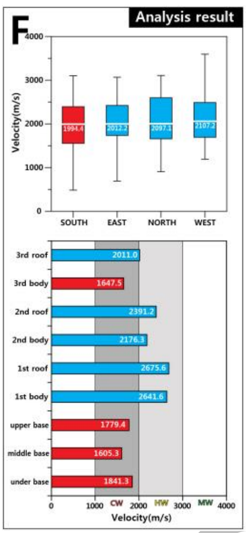

Figure 1. (F) Average ultrasonic velocity according to the elevated position of the stone elements

The ultrasonic velocity measurement has been conducted to the pagoda in order to determine physical strength of the stones. The obtained velocity was calculated by directions and individual stone elements (Figure 1F). The results are as follows: southern part average 1994 m/s, eastern part average 2012 m/s, northern part average 2097 m/s, and western part average 2107 m/s.

Using the results, the weathering degree was determined. The results showed that the overall degree is class 4 (Highly weathered) with the exception of the southern face, which is class 5. The basement and the 3rd body stones is class 5 (Completely weathered), whereas the 1st body and roof stones, 2nd body and roof stones, and 3rd roof stones are categorized as class 4 (Figure 1F). Especially, the foundation stones showed much lower ultrasonic velocity. This referred to more granular disintegration and surface deterioration of the stones compared to other parts.

4. Effectiveness evaluation for stone consolidation

The treatment materials of Hyeon-ri Three-storied stone pagoda were severely deteriorated so that it is required further conservation intervention. Prior to the retreatment, indoor and outdoor application tests to determine the stability and the effectiveness of the consolidant were performed. Firstly, we analyzed the changes of the mechanical properties and strength of the stones before and after the consolidation.

The four consolidants were selected: Wacker OH 100, Remmers OH, Remmers 100 and Remmers 300. We have chosen to use the vacuum impregnation method for consolidation. Although this method is limited to indoor application, it performs the maximum effectiveness. The treatment environment was as follows: temperature 20℃, relative humidity 40 ~ 50 percent. After the consolidation, we put the samples until there was no change in weight to settle the consolidation reaction. When the samples completed its reaction, the physical properties were measured and compared to the samples before the consolidation.

Of the 4 types of consolidants, Wacker OH 100, which had the highest silicate content, showed the highest penetration rate at 17.0 g. Remmers 100, with the lowest silicate content, showed the lowest penetration rate at 12.5 g. Therefore, we could estimate that higher silicate contents would produce higher consolidating effect. Also, in every case of the testing, the weight continually decreased as time went on, but stabilized after 40 days.

After the treatment, porosity and absorption rate decreased by 3.33 percent and 1.41 percent, respectively, and the ultrasonic velocity increased by approximately 677 m/s. The compressive and tensile strength increased by 45.97 MPa and 2.58 MPa, respectively, and Young's Modulus rate has also increased (Figure 2). We can conclude that the physical properties have improved due to the penetration of the consolidandts by filling the pores and cavities in the stones.

Focused on the individual consolidants, the Wacker OH 100 showed the highest increasing rate for the porosity and absorption rate, whereas Remmers 300 showed the highest increasing rate for the ultrasonic velocity. Remmers 300 showed comparably higher increasing rate for compressive strength and Poisson's Coefficient, while all 4 types showed similar characteristic changes for tensile strength (Figure 2). Therefore we concluded that Wacker OH 100 and Remmers 300 produced the best reinforcement effect. They both contain 99~100 percent ethyl silicate contents, and we now understand that the ethyl silicate concentration plays a large role in producing favorable consolidating effect (Song et al. 2009a; Han et al. 2008).

5. In-situ application for stone consolidation

Up until recently, it was difficult to gain satisfactory efficiency from the preservation and restoration methods and treatments used for the stone cultural heritages. This was because there was not enough information and understanding about the stone materials and weathering characteristics, and there were not enough scientific examinations and tests to develop a suitable consolidating agent and application methods (Song et al. 2009a). In-situ application simulation tests were performed on outdoor bedrocks with similar weathering degree and stone properties as the Hyeon-ri Three-storied stone pagoda, using Wacker OH 100 and Remmers 300, which showed the best performance in the laboratory experiments.

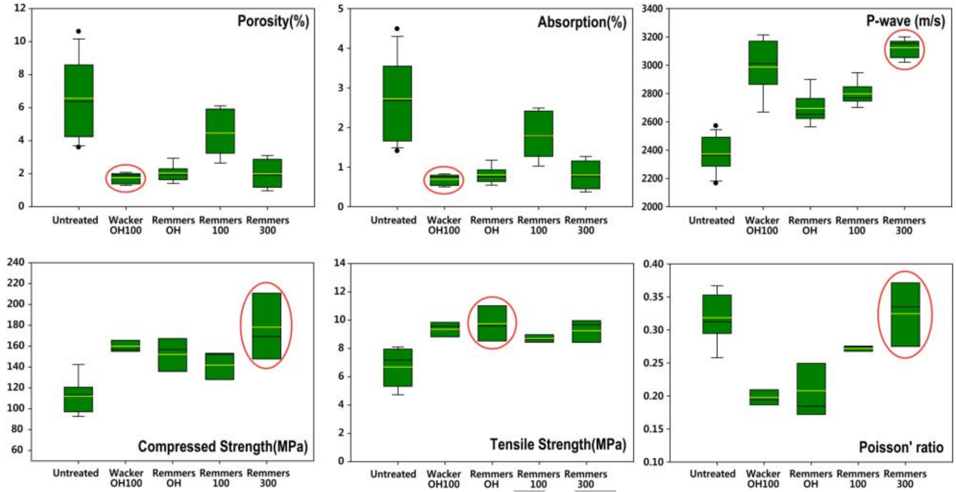

Figure 2. Physical properties of the untreated and treated samples by consolidants

The selected site is a bedrock surrounding Yeondaeam, near the Samji-dong stone pagoda. In-situ application areas were divided into 'highly weathered areas' (areas 1, 2, 3) and 'completely weathered areas' (area 4, 5, 6). Two different methods were used to see the difference in results that are spray and brush applications. The consolidation treatment progressed over three trials (Song et al. 2009a), and the changes in material characteristics were monitored using the ultrasonic velocity (PUNDIT PLUS).

After the application, the ultrasonic velocity increased in all areas. However, after the 3rd application, the rate began to slowly decrease (Figure 3A, 3B). This means that the pores and cavities of the stone were filled with the consolidant during the application, but it slowly regained the cavity space after a period of time.

The ultrasonic velocity increasing rate was calculated by dividing the velocity difference between the pre-treatment and post-treatment, with the pre-treatment value. The results are as follows: After the 3rd application, there was an increase of 26.6% in area 1, 22.2% in area 2, 23.7% in area 3, 40.1% in area 4, 34.9% in area 5, 37.6% in area 6 (Figure 3C). Overall, the 'completely weathered areas' (areas 4, 5, 6) showed a higher increasing rate compared to the 'highly weathered areas' (areas 1, 2, 3).

By treatment methods, the brush application method produced a 5% higher increasing rate. Wacker OH 100 brush method produced the best results for areas 1, 2, 3. Remmers 300 brush method produced the best results for areas 4, 5, 6 (Figure 3C). During the monitoring after the application, Wacker OH 100 spray method produced the lowest ultrasonic velocity decreasing rate. However, when comparing the rate change, we can see that the Remmers KSE 300 brush method performed the best consolidating effect (Figure 3D).

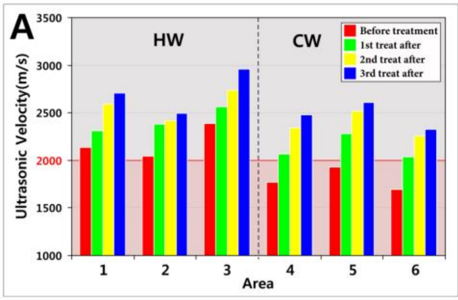

Figure 3. (A) Ultrasonic velocity during and after in-situ consolidation of sandstone. Ultrasonic velocity by application areas during the consolidation

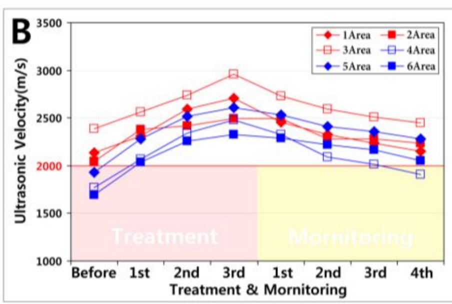

Figure 3. (B) Ultrasonic velocity by application areas during the consolidation

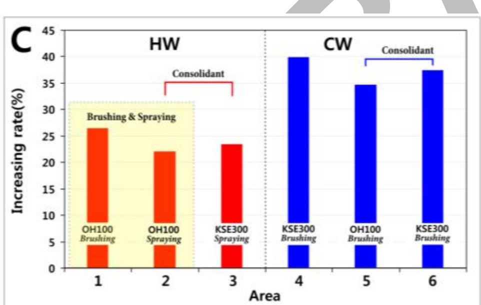

Figure 3. (C) Increased ultrasonic velocity by consolidants and application methods

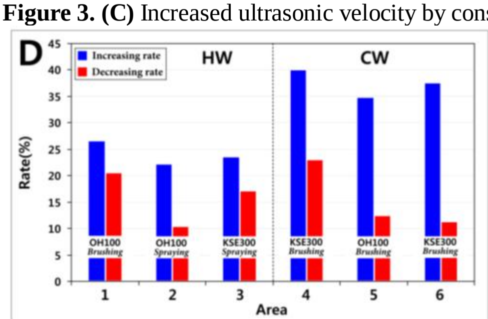

Figure 3. (D) Ultrasonic velocity change during and after the consolidation

6. Discussion and Conclusions

By observing the changes of the porosity, absorption rate and ultrasonic velocity, before and after laboratory experiment with the sandstone samples from the Yeongyang area, Wacker OH 100 and Remmers 300 produced the best consolidating results. Based on these results, by applying the consolidants at the field sites, the ultrasonic velocity increased by 14.5~28.2% by using both Wacker OH 100 and Remmers 300. Furthermore, as the number of application trials of the consolidants increased, it showed a consistent increasing rate. Therefore, we can verify that a minimum of three trials process would be effective for the surface consolidation of the stone cultural heritages.

Regardless of which consolidant or method is used, the sandstones with higher weathering degree showed immediate results after the application process. This is because as the sandstones suffer more deterioration, there are more pores and cavities formed within. And by applying the consolidant, the pore space is filled and strengthened. Of the application methods, the brush method proved to be better than the spray method. The spray method has a tendency to disperse into the air during the application process with the volatile components of the consolidant, and the surface contact ratio is significantly poor than that of the brush method, producing a less penetration.

The Hyeonri Three-storied stone pagoda, as well as other cultural heritages of similar material and deterioration, requires consolidation for highly deteriorated areas. And a minimum of three trials of applications is also deemed necessary to maximize the binding effect of loosened minerals, and it would effectively increase the strength of the stone.

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