Reinforced Strength Evaluation of Binding Material for the Restoration of Chinese Ancient Lacquer Furniture

Tianxing Zhang,[a,b] Gao Ting,[a] Zhihui Wu,[b]* and Tian Sun [c]

Lacquer, bone glue, and poly(vinyl acetate) (PVAc) were selected in this work as the reinforced binding components for the restoration of lacquer furniture. Three response variables related to the strength of the binding material were studied: cohesive strength of lacquer film, binding situation, and the permeation of adhesive. In addition to mechanical tests, specimens were observed directly and by scanning election microscopy (SEM). The cohesive strength of lacquer film attached by lacquer, bone glue, and PVAc was evaluated on specimens with three kinds of ground layer, including stucco with pig-blood, stucco with lacquer, and the ground layer with titanium dioxide. The permeation of lacquer, bone glue, and PVAc could be determined by SEM. The results shows that strong reinforcement can be achieved by strong cohesive strength of lacquer film, a suitable binding situation, and suitable permeation of the adhesive. Intermediate strength is obtained in the case of intermediate cohesive strength, an intermediate binding situation, and less then optimal permeation. Weak reinforcement results from weak cohesive strength, a poor binding situation, and insufficient permeation.

Keywords: Reinforced strength; Cohesive strength; Binding situation; Adhesive permeation; Ancient lacquer furniture; Reinforced strength evaluation

*Contact information: a: WuYi University, 529020, China; b: Nanjing Forestry University, Nanjing, 210037, China; c: Science and Technology Institute for Conservation of Historical Relics of Nanjing Museum, Nanjing, 210037, China; * Corresponding author: zhihuiwunl@sina.com*

INTRODUCTION

The restorative reinforcement of fallen-off lacquer film of Chinese ancient lacquer furniture requires that the fallen-off lacquer film be re-attached to the ground layer covering the ancient lacquer furniture by use of an adhesive (Lu *et al.* 2003; Qiao 2015). The adhesive and ground layers are significant factors in the restorative reinforcement. The adhesive includes lacquer, bone glue, and poly-(vinyl acetate) (PVAC) (Lyoo *et al.* 1997; Nie 2004). There are three kinds of ground layers: stucco with pig blood (Liu *et al.* 2016), stucco with lacquer (Jiang *et al.* 2016), and the ground with titanium dioxide. Previous researchers have focused on the process of restorative reinforcement for the lacquer film on the three kinds of ground layers (Burmester 1988; Ma *et al*. 2002; Wu 2003; Fan 2006; Yue 2017), but different adhesives provide distinctive strength of reinforcement on stucco with pig-blood, stucco with lacquer, and the ground layer with titanium dioxide. There has been little research on the reinforced strength of adhesives when the lacquer, bone glue, and PVAc are bound to ground layers including stucco with pig blood, stucco with lacquer, and stucco with titanium dioxide.

This work used lacquer (Miyakoshi *et al.* 1999; Terada *et al*. 1999; Zhang 2001), bone glue (Su *et al*. 2013), and PVAc (Budhlall *et al.* 2001; Qin 2004). Three evaluation indexes were established by measuring the cohesive strength of lacquer film, the binding situation of the adhesive, and the permeation of adhesive. The cohesive strength of lacquer film was tested mechanically. The binding situation of adhesive includes the formation of

a film of lacquer, and the possibility of gelation phenomenon. In particular, the bone glue tends to lose its liquidity with decreasing temperature. The results presented herein can establish a standard for reattachment of lacquer film in the reinforced restoration of Chinese ancient lacquer furniture.

EXPERIMENTAL

Materials

The experimental materials included adhesive, lacquer film, and woodblocks with stucco. The adhesive contained either lacquer, bone glue, or PVAc. The lacquer was harvested from a wild lacquer tree (Shengzong Xiao) in Shanxi province, China. The bone glue was made by Mingyong Gan, a lacquer furniture restorer in Beijing. The PVAc is polyvinyl acetate emulsion from Peking Jicheng Scientific and Technical Corporation. Its viscosity is more than 1000, and the processing temperature is 5 to 40 ℃. The lacquer film was recovered from damaged ancient lacquer film, and the ground layer was maintained with a thickness of 1 to 1.5 mm. A total of 90 pieces of sizes 30 mm × 30 mm were used (Table 1, Fig. 1). The woodblocks needed a covered ground layer including stucco with pig blood, lacquer, and titanium dioxide. The stucco with pig blood was a mixture of pig blood, water, and wahui, where wahui is powder from tiles, which is a common material in the ground layer of Chinese ancient lacquer furniture. The stucco with lacquer was a mixture of lacquer, water, and wahui. The ground layer with titanium dioxide was a mixture of PVAc, water, and titanium dioxide. Figure 1 shows the different woodblocks covered stucco with pig-blood, stucco with lacquer and ground with titanium dioxide, the function of these woodblocks is as base to cohere the lacquer film, the numbers are 90 pieces and the sizes are 50 mm ×50 mm.

Table 1. Quantities of Lacquer Film

Adhesive	Stucco with Pig Blood	Stucco with Lacquer	Stucco with Titanium Dioxide
Lacquer	10 pieces	10 pieces	10 pieces
Bone glue	10 pieces	10 pieces	10 pieces
PVAc	10 pieces	10 pieces	10 pieces

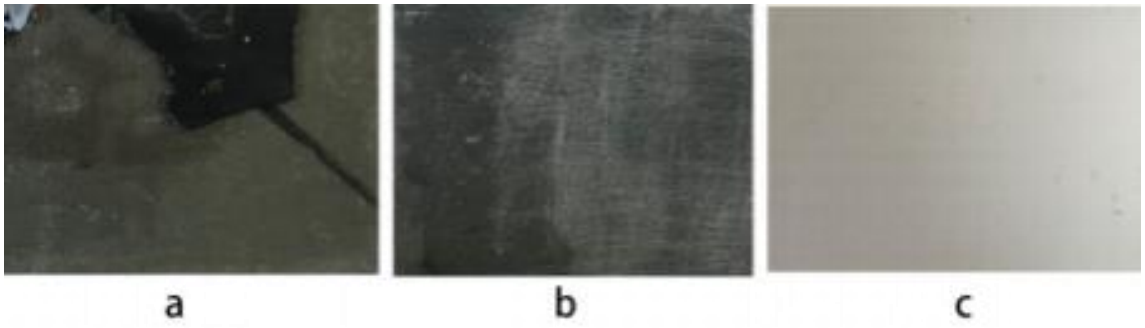


Fig. 1. Woodblocks covered with ground layers of stucco with (a) pig blood, (b) lacquer, and (c) titanium dioxide.

Mechanical Test Machine

The maximum load of lacquer film was tested by a type AG-IC mechanical test machine (Shimadzu, Tokyo, Japan), and the cohered strength of lacquer film ($\sigma_{\perp}$) was calculated according to Eq. 1,

$$\sigma_{\perp} = \frac{P_{max}}{l \times b} \quad (1)$$

where P_{max} is the maximum loading of lacquer film; l and b demonstrate the effective cohered area that touches the mechanical test machine (Fig. 2). The effective cohered area of 20 mm × 20 mm was used in the testing of cohered strength for lacquer film. Figure 2a shows the location of lacquer film that is in the middle of woodblock covered ground layer and accessories, and Fig. 2b shows the peeling of the sample.

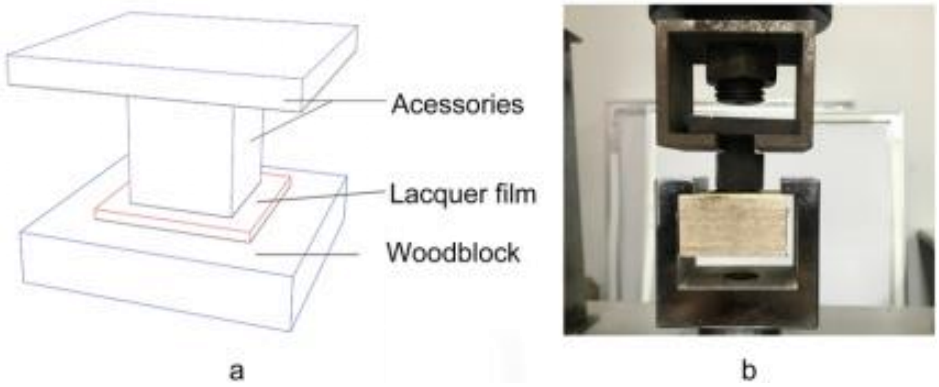


Fig. 2. Effective area showing of lacquer film

SEM

The binding situation of adhesive was observed using a Hitachi TM1000 scanning election microscope (Tokyo, Japan). The formation film of lacquer, the gelation phenomenon of bone glue, and the condition of PVAc were included in the binding situation of adhesive. Successful formation film can increase the reinforced strength of lacquer. The gelation phenomenon gives rise to the development of reinforcing strength of bone glue.

RESULTS AND DISCUSSION

Cohesive Strength of Lacquer Film

Table 2 shows that the lacquer films exhibited different cohesive strength on distinctive ground layers by the binding of lacquer, bone glue, and PVAc. The cohesive strength was categorized as strong, intermediate, or weak as defined by the ranges of above 0.44 MPa, between 0.34 and 0.35 MPa, or below 0.17 MPa, respectively.

Table 2. Average Cohered Strength of Lacquer Film

Adhesive	Stucco with Pig Blood	Stucco with Lacquer	Ground Layer with Titanium Dioxide
Lacquer	0.42 MPa	0.40 MPa	0.41 MPa
Bone glue	0.35 MPa	0.16 MPa	0.34 MPa
PVAc	0.17 MPa	0.09 MPa	0.44 MPa

The lacquer film cohered by lacquer had a strong cohesive strength on the three kinds of ground layer including stucco with pig-blood, stucco with lacquer, and ground layer with titanium dioxide. The lacquer film cohered bone glue had intermediate cohesive strength on the stucco with pig-blood and ground layer with titanium dioxide, and it had weak cohesive strength on the stucco with lacquer. The lacquer film cohered by PVAc had weak strength on the three kinds of ground layer including stucco with pig-blood, stucco with lacquer, and ground layer with titanium dioxide.

Binding Situation of Adhesive

The binding situation of adhesive includes the formation a film of lacquer and the gelation phenomenon of bone glue. Adhesive binding on the three kinds of ground layer are shown in Fig. 3. The red area demonstrates the formation film of lacquer and the gelation of bone glue. The lacquer exhibited good film formation on the three kinds of ground layer. The bone glue exhibited a slight gelation phenomenon on the stucco with pig-blood and ground layer with titanium dioxide, and there was evidence of serious gelation on the stucco with lacquer.

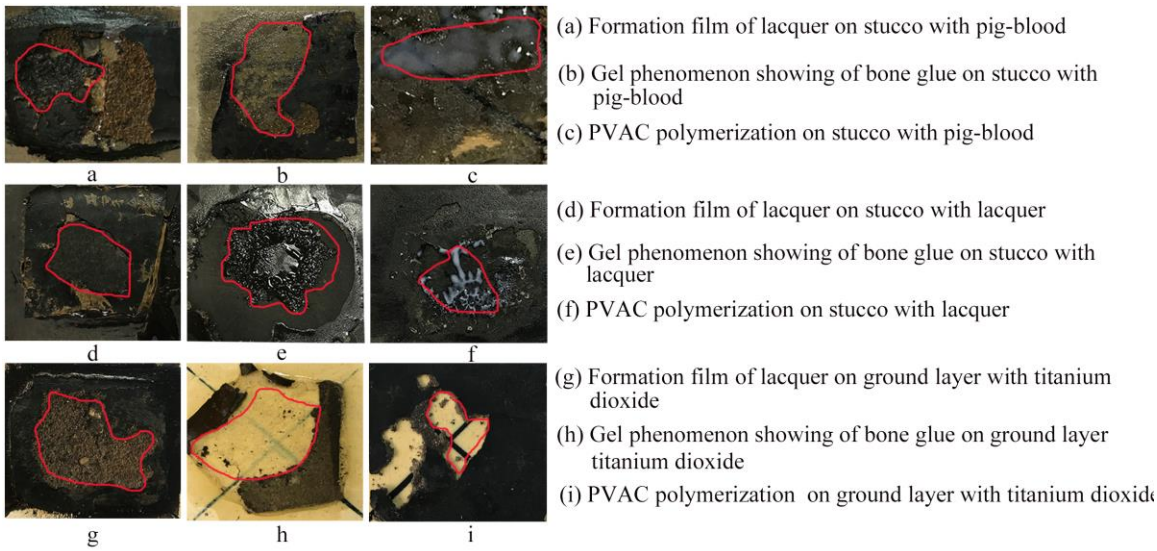


Fig. 3. Situation comparison of adhesive

The formation of the film of lacquer and the gelation phenomenon of the bone glue are the manifestations of binding situation of adhesive. The successful formation of the lacquer film and the bone glue without gelation together imply that the lacquer film has achieved a good binding situation of the adhesive. On the other hand, the unsuccessful formation of the lacquer film and the bone glue with slight or serious gelation indicate that the lacquer film has an intermediate or bad binding situation of the adhesive. The binding situation of adhesive impacts the cohesive strength of lacquer film, and a good binding situation can increase the cohesive strength of lacquer film, whereas an intermediate or bad binding situation can decrease the cohesive strength of lacquer film. It is apparent from Table 2 that the cohesive strength of lacquer film attached by lacquer, bone glue, and PVAc had good cohesive strength on the three kinds ground layers and by PVAc on the ground layer with titanium dioxide. So it was judged that the binding situations of lacquer and PVAc were of good quality on the same ground layers. The lacquer film attached by bone glue had an intermediate cohesive strength on stucco with pig-blood and ground layer with

titanium dioxide, so that the bone glue had slight gelation on the same ground layers, and the binding situation of bone glue was intermediate. The lacquer film attached by bone glue had poor cohesive strength on the stucco with lacquer and by PVAc on the stucco with pig-blood and stucco with lacquer, so that the binding situation of bone glue and PVAc was judged to be bad on the same ground layer. The analysis shows that the binding situation of lacquer to bone glue and PVAc is related with cohesive strength of lacquer film.

Permeation Situation of Adhesive

The permeation of lacquer, bone glue, and PVAc is shown in the Fig. 4 on the stucco with pig blood, stucco with lacquer, and ground layer with titanium dioxide. The lacquer achieved good permeation on the three kinds of ground layer. The bone glue exhibited good permeation on the stucco with pig-blood and ground layer with titanium dioxide, but it showed weak permeation stucco with lacquer. The PVAc showed weak permeation on the stucco with pig blood, stucco with lacquer, and had good permeation on ground layer with titanium dioxide.

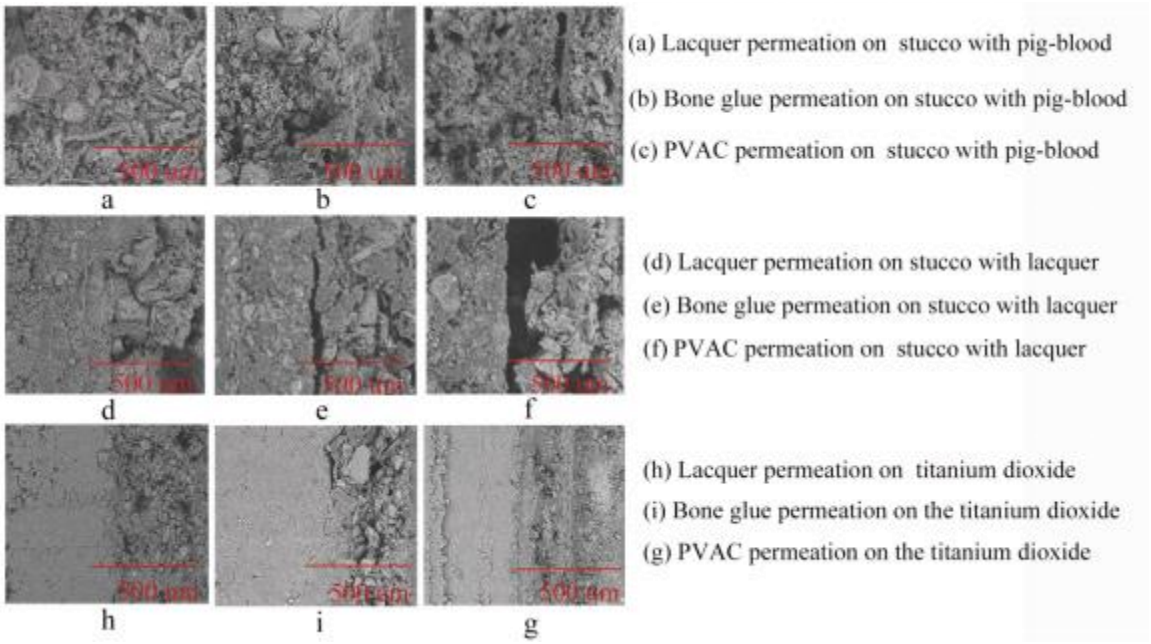


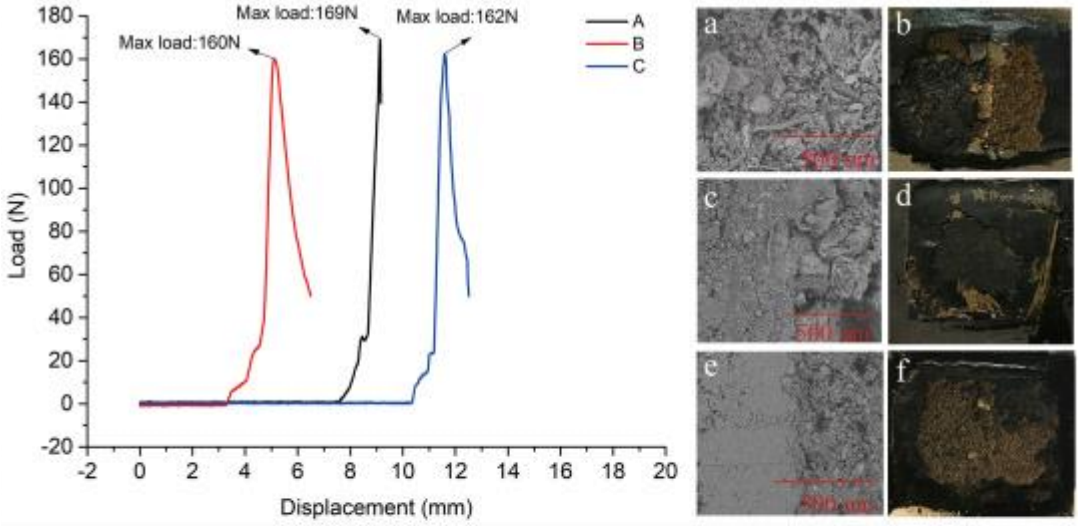
Fig. 4. Permeation comparison of adhesive

The permeation of adhesive can be observed by observing the gap zone between the lacquer film and ground layer covered woodblocks. The permeation of adhesive is judged to be good if there is no gap, the permeation of adhesive is intermediate if there is a slight gap, and the permeation of adhesive is bad with a serious gap. Panels a, b, h, and g of Fig. 4 exhibit good permeation with no gap. Panels a, b, and h of Fig. 4 correspond to the permeation of lacquer on the three kinds ground layer. Part the g of Fig. 4 shows the permeation of PAVC on the ground layer with titanium dioxide. Panels b and i of Fig. 4 exhibit intermediate permeation of bone glue with a slight gap on the stucco with lacquer. Panels c, e, and f of Fig. 4 indicate bad permeation with a serious gap. Part the e of Fig. 4 corresponds to the permeation of bone glue on the stucco with lacquer, whereas Panels c and f of Fig. 4 correspond to the permeation of PVAc on the stucco with pig blood and stucco with lacquer.

There are three permeation degrees including good, intermediate, and bad for adhesive. Adhesives with good permeation included lacquer attached to the three kinds of ground layer and PVAc adhered to the ground layer with titanium dioxide. An adhesive with intermediate permeation was bone glue adhered on the stucco with pig blood and ground layer with titanium dioxide. Adhesives with bad permeation were bone glue cohered on the stucco with lacquer and PVAc cohered on the stucco with pig blood and stucco with lacquer. Good permeation of adhesive produces high strength of attachment, intermediate permeation of adhesive produces intermediate cohesive strength, and bad permeation of adhesive gives rise to weak cohesive strength. On the stucco with pig blood, the good permeation of lacquer produced strong cohesive strength of lacquer film, the intermediate permeation of bone glue produced intermediate cohesive strength of lacquer film, and bad permeation of PVAc gave rise to the weak cohesive strength of lacquer film. On the stucco with lacquer, the good permeation of lacquer yielded good cohesive strength of lacquer film, whereas the bad permeation of bone glue and PVAc gave rise to weak cohesive strength of lacquer film. On the ground layer with titanium, the good permeation of lacquer and PVAc produced strong cohesive strength of lacquer film, whereas the intermediate permeation of bone glue generated intermediate cohesive strength of lacquer film.

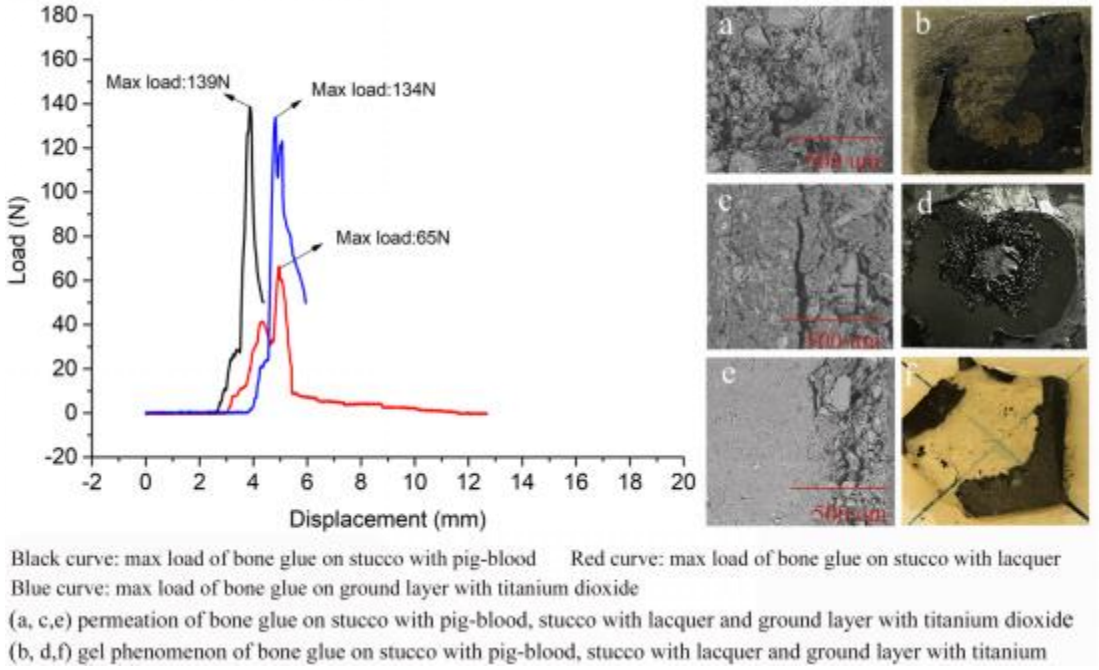
Evaluation for Reinforced Strength of Adhesive

Figures 5, 6, and 7 show the relationships among the three indexes including cohesive strength of the lacquer film, the binding situation of adhesive, and the adhesive permeation on the different types of ground layer. Tables 3, 4, and 5 are the assessment results of reinforced strength for adhesive.



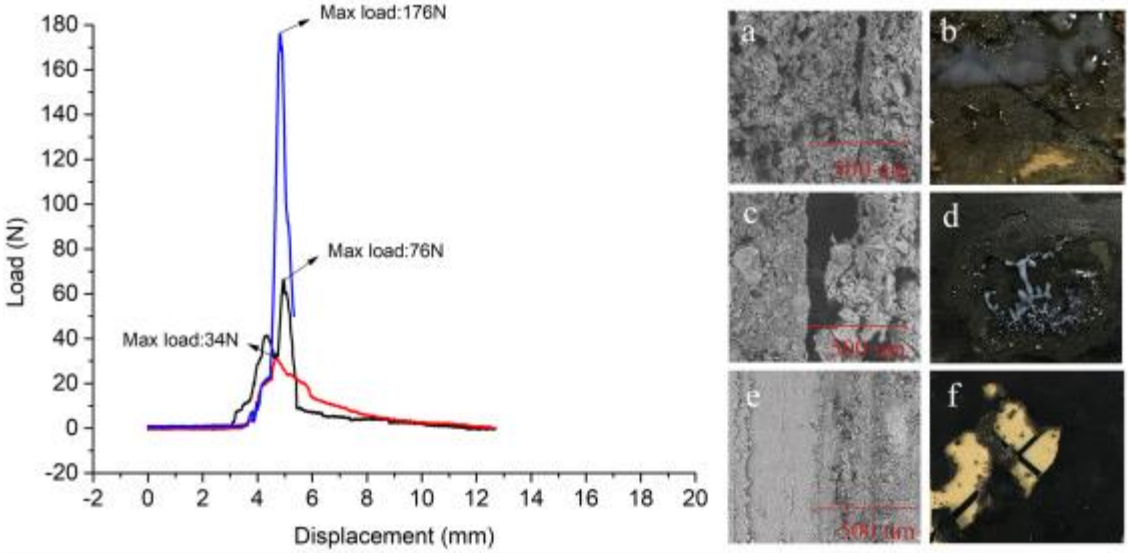
Black curve: max load of lacquer on stucco with pig-blood Red curve: max load of lacquer on stucco with lacquer
Blue curve: max load of lacquer on ground layer with titanium dioxide
(a, c, e) lacquer permeation on stucco with pig-blood, stucco with lacquer and ground layer with titanium dioxide
(b, d, f) formation film of lacquer on stucco with pig-blood, stucco with lacquer and ground layer with titanium dioxide

Fig. 5. Complex showing of three indexes for lacquer



Black curve: max load of bone glue on stucco with pig-blood Red curve: max load of bone glue on stucco with lacquer
Blue curve: max load of bone glue on ground layer with titanium dioxide
(a, c,e) permeation of bone glue on stucco with pig-blood, stucco with lacquer and ground layer with titanium dioxide
(b, d,f) gel phenomenon of bone glue on stucco with pig-blood, stucco with lacquer and ground layer with titanium

Fig. 6. Complex showing of three indexes for bone glue



Black curve: max load of PVAC on stucco with pig-blood Red curve: max load of PVAC on stucco with lacquer
Blue curve: max load of PVAC on ground layer with titanium dioxide
(a, c, e) PVAC permeation on stucco with pig-blood, stucco with lacquer and ground layer with titanium dioxide
(b, d, f) PVAC ploymerization on stucco with pig-blood, stucco with lacquer and ground layer with titanium dioxide

Fig. 7. Complex showing of three indexes for PVAc

Table 3. Evaluation Results of Reinforced Strength for Lacquer

Stucco with pig blood			Stucco with lacquer			Ground layer with titanium dioxide		
Indexes		Evaluation Results	Indexes		Evaluation Results	Indexes		Evaluation Results
Cohesive strength of lacquer film	Strong	strong	Cohesive strength of lacquer film	Strong	Strong	Cohesive strength of lacquer film	Strong	Strong
Formation film degree of lacquer	Well		Formation film degree of lacquer	Well		Formation film degree of lacquer	Well	
Permeation	Well		Permea-tion	Well		Permeation	Well	

Table 4. Evaluation Results of Reinforced Strength for Bone Glue

Stucco with pig blood			Stucco with lacquer			Ground layer with titanium dioxide		
Indexes		Evaluation Results	Indexes		Evaluation Results	Indexes		Evaluation Results
Cohesive strength of lacquer film	Inter-mediate	Inter-mediate	Cohesive strength of lacquer film	Weak	Weak	Cohesive strength of lacquer film	Inter-mediate	Inter-mediate
Formation film degree of lacquer	Slightly		Formation film degree of lacquer	Serious		Formation film degree of lacquer	Slightly	
Permeation	Inter-mediate		Permeation	Bad		Permeation	Inter-mediate	

Table 5. Evaluation Results of Reinforced Strength for PVAc

Stucco with pig blood			Stucco with lacquer			Ground layer with titanium dioxide		
Indexes		Evaluation Results	Indexes		Evaluation Results	Indexes		Evaluation Results
Cohesive strength of lacquer film	Weak	Weak	Cohesive strength of lacquer film	Weak	Weak	Cohesive strength of lacquer film	Strong	Strong
Formation film degree of lacquer	Bad		Formation film degree of lacquer	Bad		Formation film degree of lacquer	Well	
Permeation	Bad		Permeation	Bad		Permeation	Well	

Figure 5 and Table 3 show the relation of reinforced strength of lacquer and three indexes. Figure 6 and Table 4 provide the relation of reinforced strength of bone glue and three indexes. Figure 7 and Table 5 show the relation of reinforced strength of PVAc and

two indexes. The reinforced strength of adhesive including lacquer, bone glue, and PVAc is evaluated by three indexes including cohered strength of lacquer film, the binding situation, and permeation. From the three figures it is apparent that the lacquer achieved strong cohesive strength of lacquer film, good film formation film, and effective permeation on stucco with pig-blood, stucco with lacquer, and ground layer with titanium dioxide (Fig. 5), so that the lacquer exhibited strong reinforced strength. Figure 6 indicates that the bone glue achieved intermediate cohesive strength of lacquer film, slight gelation, and intermediate permeation on stucco with pig-blood and ground layer with titanium dioxide, whereas it achieved weak cohesive strength, serious gelation, and bad permeation on stucco with lacquer, so that the bone glue had intermediate reinforced strength on the stucco with pig-blood and ground layer with titanium dioxide, and it exhibited weak reinforced strength on the stucco with lacquer. Figure 7 demonstrates that the PVAc had weak cohered strength and bad permeation on the stucco with pig-blood and stucco with lacquer, and has strong reinforced strength and good permeation on the ground layer with titanium dioxide, so that the PVAc exhibited weak reinforced strength on stucco with pig-blood and stucco with lacquer, and had strong reinforced strength on ground layer with titanium dioxide.

CONCLUSIONS

1. The reinforced strength of lacquer, bone glue, and poly-(vinyl acetate) (PVAc) is related to three factors including cohesive strength of the lacquer film, the binding situation of the adhesive, and the adhesive permeation.
2. The lacquer achieved strong reinforcement strength with strong cohesive strength of the lacquer film, successful film formation, and good permeation on the stucco with pig-blood, stucco, and lacquer with a ground layer of titanium dioxide.
3. The bone glue achieved intermediate reinforcement with intermediate cohesive strength of lacquer film, slight gelation, and intermediate permeation on the stucco with pig-blood and ground layer with titanium dioxide, and achieved weak reinforcement with intermediate cohesive strength of lacquer film with weak cohesive strength of lacquer film, serious gelation, and bad permeation on the stucco with lacquer.
4. The PVAc adhesive can achieve strong reinforcement with strong cohesive strength of the lacquer film and good permeation into the ground layer with titanium dioxide. It achieved weak reinforcement with intermediate cohesive strength of lacquer film and bad permeation on the stucco with pig-blood and lacquer.

ACKNOWLEDGMENTS

The author appreciated Ming yong Gan and Run da Zhou who provided the support of material including lacquer and bone glue and technique that the sample of wood blocks with putty layer were made, the Jian lin Zhou who provided the lacquer film making use of stripping is greatly appreciated.

REFERENCES CITED

Budhlall, B. M., Suodol, E. D., and Dimonie, V. L. (2001). "Role of grafting in the emulsion polymerization of vinyl acetate with poly(vinyl alcohol) as an emulsifier. I. Effecting of the degree of blockiness on the kinetics and mechanism of grafting," *Journal of Polymer Chemistry* 39, 3633-3654. DOI: 10.1002/pola.10016

Burmester, A. (1988). "Technical studies of Chinese lacquer," in: *Urushi: Proceedings of the 1985 Urushi Study Group*, Getty Conservation Institute, Los Angeles, pp. 163-188.

Fan, T. F. (2006). *Research on the Conservation and Reattachment of Han Dynasty Colored Painting*, Ph.D. Dissertation, Shanxi North University, Taiyuan, China.

Jiang, C. G., She, L. Z., Mo, Z., and Jin, P. J. (2016). "Analysis of the unearthed lacquer from Feng Peng Ling M1 in Changsha," *Journal of Sciences of Conservation and Archaeology* 28(1), 113-117.

Liu, L., Wu, H., Liu, W. X., Gong, D. C., and Zhu, Z. Y. (2016). "Lacquering craft of Qing Dynasty lacquered wooden coffins excavated from Shanxi, China – A technical study," *Journal of Cultural Heritage* 20, 676-681.

Lu, Y. L., Han, J. Q., Zhang, L., and Ma, Q. L. (2003). "The strength material and restorative method of the rotten lacquer ware for the dried area of Chinese north," *Journal of Science of Conservation and Archaeology* 15(8) 31-34.

Lyoo, W. S., Lee, C. J., Park, K. H., Kim, N., and Kim, B. C. (1977). "Preparation and molecular structure of polyvinyl alcohol by low temperature bulk polymerization of vinyl acetate and saponification," *Journal of International Journal of Polymeric Materials and Polymeric Biomaterials* 46 (1-2) 181-194. DOI: 10.1080/00914030008054852

Ma, Q. L., Lu, Y. L., Hu, Z. D., Chen, X. G., and Zhang, L. (2002). "The researching of soft method for the lacquer utensil of Chinese north," *Journal of Science of Conservation and Archaeology* 12(2), 31-35.

Miyakoshi, T., Nagase, K., and Yoshida, T. (1999). *Progress of Lacquer Chemistry*, IPC Publisher, Tokyo.

Nie, J. (2004). *Investigation of Lacquering Craft and Conservation of Lacquer Products in Han Dynasty*, Ph.D. Dissertation, Minzu University of China, Beijing, China.

Qiao, A. M. (2015). "Restoration and conservation of Chinese ancient lacquerware," *Journal of Academic Research* 3, 106-107.

Qin, W. K. (2004). *Study on the Influencing Factors of the Adhesive Strength of the PVAC*, Ph.D. Dissertation, Guangxi University, Nanning, China.

Su, X. X., Guo, M. Y., Zhang, D., and Mao, M. (2013). "Research of composition and property for the liquid of bone glue," *Journal of China Adhesives* 22(8), 32-35.

Terada, T., Oda, K., Oyabu, H., and Asami, T. (1999). *Lacquer—the Science and Practice*, Rikou Publisher, Tokyo.

Wu, S. Q. (2003). *M13 Dehydration and Restoration of Unearthed Lacquer Ware*, Cultural Relics Press, Beijing.

Yue, J. J. (2017). *Research on the Softening of for the Painted Armour Excavated from the Tomb of the Warring State Time located in BailuZhou*, Ph.D. Dissertation, University of Science and Technology of China, Hefei, China.

Zhang, F. L. (2001). "Research of controlled technique for forming film process of lacquer," *Journal of Chinese Lacquer* 9, 1-4.

Article submitted: January 28, 2019; Peer review completed: May 14, 2019; Revised version received and accepted: May 26, 2019; Published: July 23, 2019.
DOI: 10.15376/biores.14.3.7182-7192