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Prediction of Surface Weathering of Glass Artifacts Based on Multi-Factor Analysis

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Abstract: *Glass artifacts hold significant importance in historical and cultural heritage; however, their surface weathering presents challenges for preservation and research. This study aims to analyze the mechanisms and influencing factors of surface weathering of glass artifacts. By classifying glass artifacts based on color, texture, and glass type, the weathering rates of different groups were calculated and compared. The TOPSIS model and entropy weight method were used to evaluate the weight of each factor's impact on the weathering rate and to develop a predictive model. The results indicate that glass type has the greatest impact on the weathering rate, followed by color and decoration type. Through statistical analysis of chemical composition, six elements—silicon, sodium, aluminum, lead, phosphorus, and strontium—were identified as having significant effects on weathering. The final predictive model demonstrated an accuracy of approximately 73%. This study not only provides new analytical methods and predictive models but also offers a scientific basis for conservation and restoration efforts.*

Keywords: *Glass artifacts, Surface weathering, TOPSIS model, Entropy weight method, Chemical composition analysis*

1. Introduction

The importance of glass artifacts in historical and cultural heritage cannot be overstated[1]. These ancient artifacts not only reflect the craftsmanship of their time but also record information about the society, economy, and culture of the period. However, over time, the surfaces of glass artifacts are subjected to natural environmental impacts, leading to weathering, which affects their preservation status and research value[2, 3]. Therefore, studying the mechanisms and influencing factors of surface weathering of glass artifacts is of great significance for conservation and restoration efforts.

Surface weathering refers to the process by which the surface of glass undergoes physical or chemical reactions with external substances in the natural environment, resulting in changes in its structure and composition[4]. The weathering process is influenced by various factors, including the composition, color, type of glass, and environmental conditions[5, 6]. To better understand and predict the impact of these factors on the surface weathering of glass, this study employs the TOPSIS model and the entropy weight method for a systematic analysis of the weathering rates of different glass artifacts.

In this study, glass artifacts were first classified into groups based on their color, texture, and glass type, and the weathering rate for each group was calculated. The impact of different colors and decoration types on the weathering rate was also analyzed, identifying the relationships between weathering rate and decoration type, glass type, and color. To more accurately calculate the effect of these factors on surface weathering, the TOPSIS model and the entropy weight method were used to analyze and evaluate the weights of each factor. Finally, a prediction model was developed to forecast the weathering rates of different combinations of glass artifacts, and the accuracy of the model's predictions was validated.

2. Surface Weathering Analysis and Data Processing

The data in this paper originates from http://www.mcm.edu.cn. Based on the original data and the actual situation of ancient glass, we performed data preprocessing. Specifically, data with cumulative component ratios outside the range of 85% to 105% were excluded. Data with missing values were removed, and blank fields were filled with 0. All chemical component data for colors and glass types were separated.

Furthermore, in this study, the patterns A, B, and C were assigned values of 5, 10, and 6 respectively,

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based on their proportions. Similarly, high-potassium glass and lead-barium glass were assigned values of 10 and 21 respectively, using the same method. The colors blue-green, light blue, and black were assigned values of 121, 97, and 32 respectively. Other colors were calculated and found to have no impact on glass weathering; therefore, green, dark green, light green, dark blue, and purple were all assigned a value of 0 (the larger the value, the greater the impact on weathering).

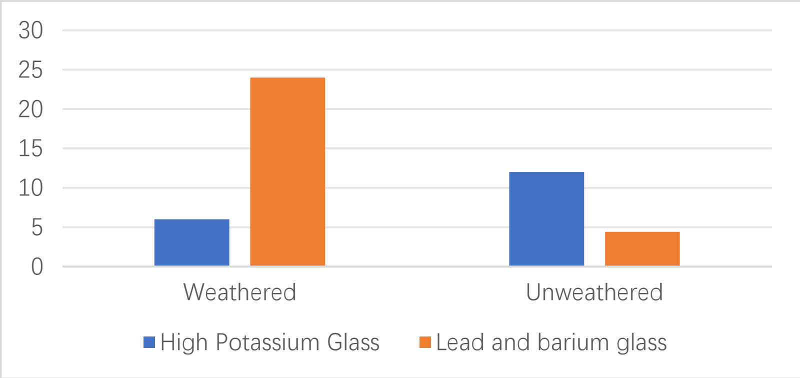

Figure 1: Weathering of high-potassium glass and lead-barium glass

From Figure 1, the weathering rate of high potassium glass and lead-barium glass can be calculated as 33.3% and 66.7%, respectively, and it can be clearly seen that the number of lead-barium glass that has been weathered is more than that of high potassium glass, and the weathering rate is also greater than that of high potassium glass. Therefore, the type of lead-barium glass has a greater weight in the weighting of the weathering rate.

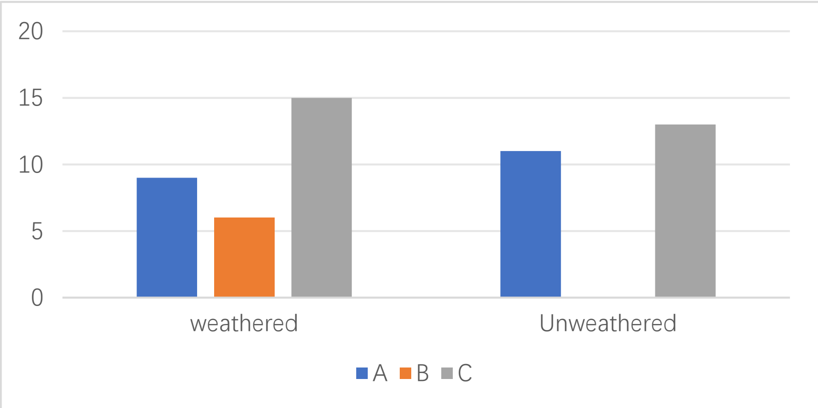

Figure 2: Weathering of decorations A, B and C

From Figure 2, the weathering rate of decorations A, B and C can be calculated, and it can be clearly seen that the number of C decorations that have been weathered is higher, but the highest weathering rate is still B decorations, so it is not difficult to see the degree of influence of A, B, and C on the weathering rate of B>C>A.

From Figure 3 it can be seen that light blue and blue-green are in the weathering type with the largest percentage of colors therefore it can be guessed that light blue and blue-green have a greater influence on weathering, and this prediction is confirmed in the subsequent calculations.

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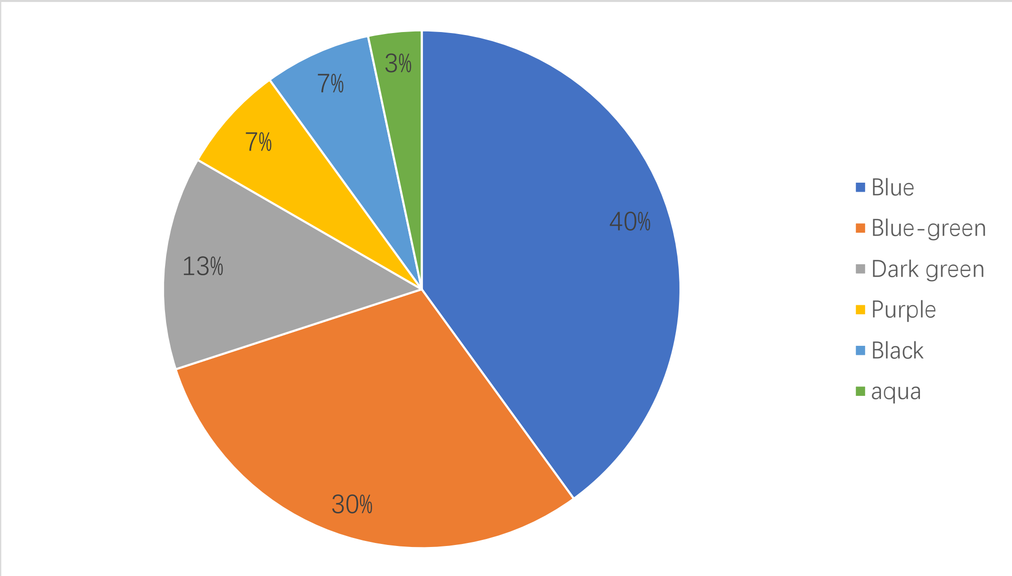

Figure 3: Color percentage of weathering types

Considering the different weathering rates of different colors in different types, we obtained the following figure after statistical analysis:

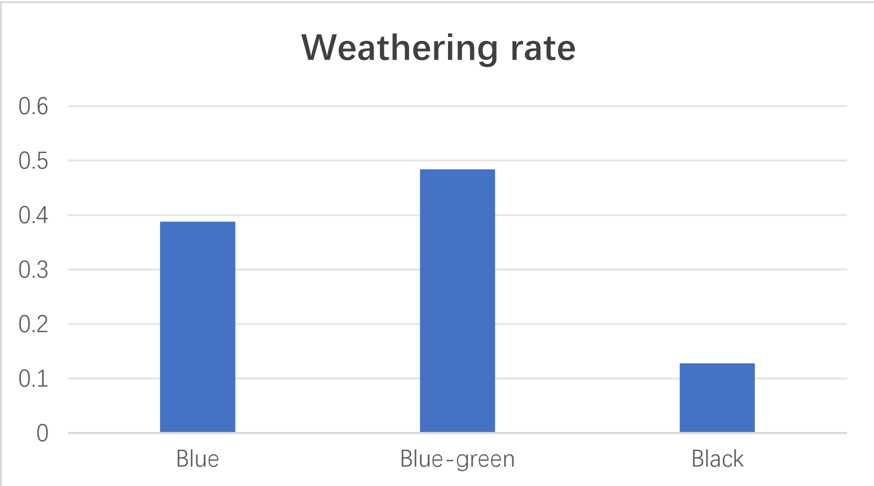

Figure 4: Weathering of colors

From Figure 4, it can be concluded that the weathering rate of blue-green is maximum 0.484, and the weathering rate of black is minimum 0.128.

3. Multi-Factor Analysis and Prediction Model of Glass Weathering Rates

In order to calculate the weathering rate for each combination (grain + glass type + color), this paper arrived at the following formula after an objective discussion:

$$P_i=\alpha_i * \beta_n * \gamma_m \ (i=1, 2, 3\ n=1, 2\ m=1, 2, 3) \quad (1)$$

which: P_i refers to the combined weathering rate, and α_i refers to the weathering rate of the decoration, the β_n refers to the weathering rate of glass types, and γ_m refers to the weathering rate of color, where α_1 , α_2 , and α_3 are the weathering rates of A, B and C, respectively. β_1 and β_2 are high potassium glass and lead-barium glass, respectively. γ_1 , γ_2 , and γ_3 blue-green, light blue, black, respectively. After calculating the weathering rate of the largest combination of B samples decorated with blue-green lead-barium glass, the combination of weathering rate of 32.3 percent.

In order to more accurately calculate the effect of grain, glass type, and color on surface weathering, we decided to use the TOPSIS model based on the entropy weight method to analyze and evaluate the

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weights of the assigned grain, glass type, and color. Compared with the traditional hierarchical analysis method and entropy weight method, the entropy weight method-TOPSIS will have a huge enhancement of objectivity, and the entropy weight method will be able to carry out an objective correction. The results are shown in Table 1.

Table 1: Entropy weighting scale

term (in a mathematical formula)	The information entropy value e	Information utility value d	weights
figure	0.969	0.031	0.069
typology	0.725	0.275	0.612
color	0.857	0.143	0.319

The weight calculation results of the entropy weight method show that the weight of ornament is 6.906%, the weight of type is 61.213%, and the weight of color is 31.882%, in which the maximum value of the indicator's weight is the type (61.213%), and the minimum value is the ornament (6.906%).

It can be obtained that the greatest influence on surface weathering is the type weight of 61.213%, the least influence is the ornamentation of 6.906%, and the influence of color on surface weathering is 31.882%.

Furthermore, this study first grouped the weathered and unweathered data and performed descriptive statistics separately to obtain a table of unweathered and weathered data, as shown in Table 2 and 3.

Table 2: Weathered Descriptive Statistics Table

Variable name	Sample size	Maximum values	Minimum value	Average value	(Statistics) standard deviation	Upper quartile	Variance (statistics)
Silicon dioxide (SiO2)	28	96.77	3.72	38.623	30.578	25.995	934.984
Sodium oxide (Na2O)	28	2.22	0	0.172	0.527	0	0.277
Potassium oxide (K2O)	28	1.05	0	0.217	0.341	0	0.116
Calcium oxide (CaO)	28	6.4	0	2.292	1.765	1.57	3.116
Magnesium oxide (MgO)	28	2.73	0	0.541	0.683	0.235	0.467
…	…	…	…	…	…	…	…

Table 3: Table of unweathered descriptive statistics

Variable name	Sample size	Maximum values	Minimum value	Average value	(Statistics) standard deviation	Upper quartile	Variance (statistics)
Silicon Dioxide (SiO2)	39	87.05	16.71	56.488	15.025	60.12	225.746
Sodium oxide (Na2O)	39	7.92	0	1.227	2.019	0	4.074
Potassium oxide (K2O)	39	14.52	0	3.017	4.764	0.26	22.692
Calcium oxide (CaO)	39	8.7	0	2.704	2.665	1.87	7.101
Magnesium oxide (MgO)	39	1.98	0	0.785	0.614	0.79	0.378
…	…	…	…	…	…	…	…

By comparing the data in Table 2 and Table 3, the non-weathering frequency histograms of each substance are drawn respectively, and according to the frequency histograms, the consecutive intervals with ≥ 80% probability are roughly selected as the reliable conditions for the non-weathering of each substance, and two by two correspondence and comparison, it can be concluded that the six chemical compositions, namely, silicon, sodium, aluminum, lead, phosphorus, and strontium, are different, and therefore we believe that the six chemical compositions are important in influencing the degree of weathering of the cultural relics factors.

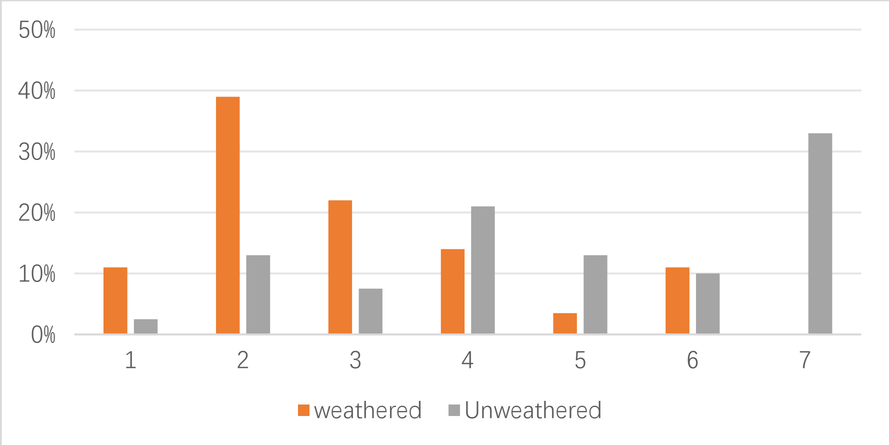

Figure 5: Histogram of weathered and unweathered frequency of alumina

Figure 5 shows the weathered and unweathered frequency histograms for alumina, and the frequency histograms for the other elements are shown in the Appendix. After comparing the data from each frequency histogram, a continuous interval of 80% probability can be used as a reliable condition for unweathering of each substance.

We divided these six indicators into positive and negative indicators, with silicon, sodium, and aluminum as positive indicator components and lead, phosphorus, and strontium as negative indicator components. (Note: We have ignored sulfur and tin because there is too little data to analyze them.)

The resulting statistical law for the more silicon, sodium, aluminum components, the greater the content of unweathered, lead, phosphorus, strontium components, the less, the greater the content of unweathered, it can be judged that: containing more silicon, sodium, aluminum components, lead, phosphorus, strontium components of the glass less unweathered content is greater, and vice versa, the weathered content is greater.

Furthermore, since there are 15 material elements in total, the prediction function is modeled as:

$$Y_i' = A_1X_{i,1} + A_2X_{i,2} + A_3X_{i,3} + A_4X_{i,4} + A_5X_{i,5} + A_6X_{i,6} + A_7X_{i,7} + A_8X_{i,8} + A_9X_{i,9} + A_{10}X_{i,10} + A_{11}X_{i,11} + A_{12}X_{i,12} + A_{13}X_{i,13} + A_{14}X_{i,14} + T \tag{2}$$

This paper solve for the coefficients separately by the results we get from the second subquestion and the ratio of the means, as shown in Table 4.

Table 4: Table of required coefficients

Required coefficient		Required coefficient		Required coefficient		Required coefficient	
A_1	1.463	A_5	1	A_9	0.46	A_{13}	1
A_2	2.126	A_6	2.157	A_{10}	1	A_{14}	1
A_3	1	A_7	1	A_{11}	0.408	T	-9.35
A_4	1	A_8	1	A_{12}	0.593		

This leads to the formula for the prediction model:

$$Y_i' = 1.463X_{i,1} + 2.126X_{i,2} + X_{i,3} + X_{i,4} + X_{i,5} + 2.157X_{i,6} + X_{i,7} + X_{i,8} + 0.46X_{i,9} + X_{i,10} + 0.408X_{i,11} + 0.593X_{i,12} + X_{i,13} + X_{i,14} - 9.35 \tag{3}$$

Constraints:$85\% < Y_i' < 105\%$

where $X_{i,j}(j = 1,2,\ldots,14)$ denotes the jth material element of the ith weathered artifact

And the correct probability of the final result is solved and tested, and finally we get our prediction probability is about 73%, and the prediction is good.

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4. Conclusion

This study meticulously analyzed the weathering rates of ancient glass artifacts by examining their chemical compositions, colors, and glass types. Through rigorous data preprocessing, we ensured the accuracy and reliability of the input data. We assigned specific values to different patterns, glass types, and colors, which allowed for a quantitative evaluation of their impact on weathering. Our findings indicated that lead-barium glass exhibits a higher weathering rate compared to high-potassium glass, emphasizing the significant influence of glass type on weathering. Additionally, the study revealed that decorations B and C, as well as the colors light blue and blue-green, have a pronounced effect on weathering rates.

By employing the entropy weight method-TOPSIS model, we objectively quantified the weights of ornamentation, glass type, and color. The analysis concluded that glass type has the highest weight in influencing weathering rates, followed by color, with ornamentation having the least impact. The multi-factor analysis and prediction model developed in this study provided a comprehensive framework for predicting weathering rates. The model demonstrated a prediction accuracy of approximately 73%, indicating its effectiveness.

In summary, this research underscores the importance of chemical composition, glass type, and color in the weathering process of ancient glass artifacts. The developed prediction model offers a valuable tool for conservators and researchers in assessing the durability and preservation needs of cultural relics.

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