# Composition Analysis and Identification of Ancient Glass Products based on Correlation Analysis and Linear Regression

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## Abstract

**Ancient glass is very easy to weathering in the process of long-time burial, resulting in the change of its composition, and then affect the identification of glass cultural relics. Therefore, in this paper, Spearman correlation analysis is used to solve the composition analysis of ancient glass products. Descriptive statistical methods and Spearman correlation analysis were used to study the statistical rule of the chemical composition content of cultural relics samples. In addition, mathematical models were established to predict the chemical composition content before and after weathering using the average value and content sum.**

## Keywords

**Glass Relics; Model; Weathering; Composition.**

## 1. Introduction

The main raw material of glass is quartz sand, but the chemical composition of glass with similar appearance is not necessarily the same, and the chemical composition content of different types of glass is significantly different [1]. Ancient glass is easily weathered due to long time of burial or the influence of the buried environment [2]. In the process of weathering, the chemical composition of the glass interior is exchanged with the chemical composition of the buried environment, which leads to the change of the composition proportion, thus affecting the correct judgment of its category[3][4].

Based on a batch of relevant data of ancient Chinese glass relics, archeologists have classified them into two types: high-potassium glass and lead-barium glass according to the proportion of chemical composition and other detection methods. The main purpose of this paper is a preliminary analysis the presence of weathering on the surface of a cultural relics of the samples were analyzed and predicted its chemical composition content of weathering before chemical component content.

## 2. Model Establishment

### 2.1. Basic Principle of Spearman Correlation Analysis

X and Y are defined as two groups of data with the same distribution and independence. The number of data elements in the two groups is N. In the two groups of random variables, the $_i$th ($1 \le i \le N$) value is represented by Xi and Yi respectively. Sort X and Y in descending or ascending order at the same time to get two element ranking sets x and y. The elements xi and yi are the ranking of Xi in X and Yi in Y. The difference of the corresponding elements in the set x and y constitutes the ranking difference set d, where $d_i = x_i - y_i$, ($1 \le i \le N$). 10. The Spearman correlation coefficient between Y can be calculated by x y or d. The rs is calculated as Eq. (1) follows [5]:

$$r_s = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i-\bar{x})^2 \sum_{i=1}^{N}(y_i-\bar{y})^2}} \quad (1)$$

The value range of Spearman correlation coefficient is [− 1, 1]. The greater the absolute value of rs, the stronger the correlation. When Spearman correlation coefficient rs<0, it is considered that there is a negative correlation between the two groups of variables discussed.

### 2.2. Chemical Composition Content Prediction

In this paper, based on descriptive statistics and using Spearman algorithm to calculate the correlation between each chemical component and whether the cultural relics are weathered, we analyze the change rule of whether there is weathering chemical component content on the surface of cultural relics, and solve the statistical rule to obtain the formula for predicting the content of each component before the weathering of cultural relics (Eq. (2)):

$$\begin{cases} x_{forecast\ medium\ term\ value\ i} = \frac{\bar{x}_{without\ weathering}}{\bar{x}_{weathering}} \cdot x_{before\ the\ predicted\ i}\left(\bar{x}_{after\ weathering\ i} \neq 0\right) \\ x_{forecast\ medium\ term\ value\ i} = \bar{x}_{without\ weathering\ i}\left(x_{after\ weathering\ i} = 0\right) \end{cases} \quad (2)$$

Wherein, $\bar{x}_{without\ weathering}$ is the average content of a certain component before weathering of this type of cultural relics, and$\bar{x}_{weathering}$ is the average content of a certain component after weathering of this type of cultural relics.

In order to ensure that the sum of the predicted proportions of each component is within the effective area and that the calculation dimensions of the same cultural relic sample before and after weathering are the same, the prediction formula should have the following constraints (Eq. (3)):

$$\sum_{i=1}^{n} x_{final\ predicted\ value\ i} \quad (3)$$

That is, use the above formula to standardize the predicted value of each component, and the final solution formula is as Eq. (4) shows:

$$x_{final\ predicted\ value\ i} = \frac{\bar{x}_{without\ weathering}}{\bar{x}_{weathering}} \cdot x_{before\ the\ predicted\ i} \cdot \frac{\sum_{i=1}^{n} x_{before\ the\ predicted\ i}}{\sum_{i=1}^{n} x_{forecast\ medium\ term\ value\ i}} \quad (4)$$

## 3. Results and Analysis

### 3.1. Effect of Weathering on Composition of Different Types of Glass

The correlation analysis of chemical composition of high potassium and lead barium glasses is shown in Table 1 and Table 2.

**Table 1.** Correlation analysis between chemical composition and weathering of high potassium glass

| Chemical component | $SiO_2$ | $Na_2O$ | $K_2O$ | CaO | MgO | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| Correlation coefficient | 0.818*** | -0.315 | −0.706*** | −0.545** | −0.602*** | −0.795*** | −0.545** |
| Chemical component | CuO | PbO | BaO | $P_2O_5$ | SrO | $SnO_2$ | $SO_2$ |
| Correlation coefficient | -0.273 | −0.543** | -0.374 | −0.602*** | −0.487** | -0.171 | -0.315 |

Note: *** is P≤0.01, ** is P ≤0.05, * is P≤0.1

**Table 2.** Correlation analysis between chemical composition and weathering of lead barium glass

| Chemical component | $SiO_2$ | $Na_2O$ | $K_2O$ | CaO | MgO | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| Correlation coefficient | −0.857*** | −0.380** | -0.241 | −0.387*** | -0.066 | −0.394*** | -0.068 |
| Chemical component | CuO | PbO | BaO | $P_2O_5$ | SrO | $SnO_2$ | $SO_2$ |
| Correlation coefficient | 0.370** | 0.734*** | 0.160 | 0.564*** | 0.413*** | -1.460 | 0.320** |

Note: *** is $P \leq 0.01$, ** is $P \leq 0.05$.

For high potassium type glass, weathering is significantly related to the content of silica $SiO_2$, potassium oxide $K_2O$, calcium oxide CaO, magnesium oxide MgO, alumina $Al_2O_3$, iron oxide $Fe_2O_3$, lead oxide PbO, phosphorus pentoxide $P_2O_5$, strontium oxide SrO.

For lead barium glass, weathering is significantly related to the content of silica $SiO_2$, sodium oxide $Na_2O$, calcium oxide CaO, alumina $Al_2O_3$, copper oxide CuO, lead oxide PbO, phosphorus pentoxide $P_2O_5$, strontium oxide SrO, sulfur dioxide $SO_2$.

## 3.2. Prediction of Chemical Composition Content of Cultural Relics before Weathering

The statistical analysis results of chemical composition content of high-potassium glass and lead-barium glass before and after weathering are shown in Table 3 and 4. The prediction results of chemical composition of high potassium glass and lead barium glass are shown in Table 5 and Table 6.

**Table 3.** Change law of descriptive statistical analysis of chemical composition of high potassium glass before and after weathering

| Chemical component | Weathering conditions | sample size | mean | standard deviation | variance | kurtosis | skewness |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | B | 12 | 67.984 | 8.755 | 76.652 | 0.536 | 1.158 |
| | A | 6 | 93.963 | 1.734 | 3.005 | -0.388 | 0.854 |
| $Na_2O$ | B | 12 | 0.695 | 1.28692 | 1.656 | 0.559 | 1.497 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |
| $K_2O$ | B | 12 | 9.3308 | 3.9203 | 15.369 | 1.9 | -1.203 |
| | A | 6 | 0.5433 | 0.44518 | 0.198 | -1.913 | -0.537 |
| CaO | B | 12 | 5.3325 | 3.09248 | 9.563 | -0.518 | -0.875 |
| | A | 6 | 0.87 | 0.48777 | 0.238 | 0.988 | 0.504 |
| MgO | B | 12 | 1.0792 | 0.67614 | 0.457 | -1.015 | -0.434 |
| | A | 6 | 0.1967 | 0.30631 | 0.094 | -1.598 | 1.014 |
| $Al_2O_3$ | B | 12 | 6.62 | 2.49151 | 6.208 | -0.492 | 0.482 |
| | A | 6 | 1.93 | 0.96449 | 0.93 | 0.181 | 0.779 |
| $Fe_2O_3$ | B | 12 | 1.9317 | 1.66669 | 2.778 | 2.568 | 1.176 |
| | A | 6 | 0.265 | 0.0695 | 0.005 | -1.418 | -0.3 |
| CuO | B | 12 | 2.4525 | 1.65999 | 2.756 | -1.058 | 0.101 |
| | A | 6 | 1.5617 | 0.93482 | 0.874 | 2.231 | 1.218 |

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|---|---|---|---|---|---|---|---|
| PbO | B | 12 | 0.4117 | 0.58899 | 0.347 | 0.418 | 1.374 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |
| BaO | B | 12 | 0.5983 | 0.9821 | 0.965 | 1.238 | 1.493 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |
| $P_2O_5$ | B | 12 | 1.4025 | 1.43396 | 2.056 | 1.876 | 1.678 |
| | A | 6 | 0.28 | 0.20995 | 0.044 | 0.372 | 0.399 |
| SrO | B | 12 | 0.0417 | 0.0484 | 0.002 | -1.452 | 0.571 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |
| $SnO_2$ | B | 12 | 0.1967 | 0.68127 | 0.464 | 12 | 3.464 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |
| $SO_2$ | B | 12 | 0.1017 | 0.18551 | 0.034 | 0.055 | 1.396 |
| | A | 6 | 0 | 0 | 0 | 0 | 0 |

Note: B means "Before weathering", A means "After weathering".

**Table 4.** Descriptive statistical analysis of chemical composition of lead-barium glass before and after weathering

| Chemical component | Weathering conditions | sample size | mean | standard deviation | variance | kurtosis | skewness |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | B | 23 | 54.6596 | 11.82859 | 139.916 | -0.538 | -0.371 |
| | A | 26 | 24.9127 | 10.60548 | 112.476 | 1.23 | 0.313 |
| $Na_2O$ | B | 23 | 1.6826 | 2.37164 | 5.625 | 0.758 | 1.287 |
| | A | 26 | 0.2162 | 0.55665 | 0.31 | 6.743 | 2.666 |
| $K_2O$ | B | 23 | 0.2187 | 0.31006 | 0.096 | 10.061 | 2.883 |
| | A | 26 | 0.1335 | 0.23997 | 0.058 | 7.793 | 2.512 |
| CaO | B | 23 | 1.3204 | 1.2847 | 1.65 | 1.03 | 1.347 |
| | A | 26 | 2.6954 | 1.65978 | 2.755 | -0.461 | 0.383 |
| MgO | B | 23 | 0.6404 | 0.54675 | 0.299 | -1.241 | 0.085 |
| | A | 26 | 0.65 | 0.70643 | 0.499 | 1.209 | 1.037 |
| $Al_2O_3$ | B | 23 | 4.4561 | 3.26245 | 10.644 | 4.233 | 1.988 |
| | A | 26 | 2.97 | 2.63427 | 6.939 | 10.638 | 2.829 |
| $Fe_2O_3$ | B | 23 | 0.7365 | 1.15473 | 1.333 | 4.768 | 2.072 |
| | A | 26 | 0.5846 | 0.73653 | 0.542 | 1.525 | 1.404 |
| CuO | B | 23 | 1.4317 | 1.96987 | 3.88 | 6.877 | 2.461 |
| | A | 26 | 2.2758 | 2.82052 | 7.955 | 4.154 | 2.101 |
| PbO | B | 23 | 22.0848 | 8.21515 | 67.489 | -0.456 | 0.62 |
| | A | 26 | 43.3138 | 12.23022 | 149.578 | 0.233 | -0.033 |
| BaO | B | 23 | 9.0017 | 5.82528 | 33.934 | 3.758 | 1.797 |
| | A | 26 | 11.8073 | 9.97827 | 99.566 | 0.838 | 1.278 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $P_2O_5$ | B | 23 | 1.0491 | 1.84706 | 3.412 | 3.724 | 2.167 |
| | A | 26 | 5.2773 | 4.1967 | 17.612 | -0.824 | 0.4 |
| SrO | B | 23 | 0.2683 | 0.24345 | 0.059 | 1.96 | 1.231 |
| | A | 26 | 0.4185 | 0.26484 | 0.07 | 0.777 | 0.544 |
| $SnO_2$ | B | 23 | 0.0465 | 0.12734 | 0.016 | 5.816 | 2.634 |
| | A | 26 | 0.0685 | 0.26945 | 0.073 | 19.787 | 4.365 |
| $SO_2$ | B | 23 | 0.1591 | 0.76316 | 0.582 | 23 | 4.796 |
| | A | 26 | 1.3662 | 4.20607 | 17.691 | 9.634 | 3.261 |

Note: B means "Before weathering", A means "After weathering".

**Table 5.** Prediction of chemical composition of high potassium glass

| Heritage sampling points | $SiO_2$ | $Na_2O$ | $K_2O$ | CaO | MgO | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| 07 | 72.789 | 0.755 | 0.000 | 7.123 | 0.000 | 7.376 | 1.346 |
| 09 | 71.617 | 0.724 | 10.555 | 3.959 | 0.000 | 4.717 | 2.430 |
| 10 | 73.452 | 0.729 | 16.575 | 1.350 | 0.000 | 2.915 | 1.988 |
| 12 | 66.278 | 0.675 | 16.851 | 4.287 | 0.000 | 4.865 | 2.054 |
| 22 | 59.803 | 0.622 | 11.374 | 9.107 | 3.143 | 10.745 | 2.283 |
| 27 | 71.938 | 0.745 | 0.000 | 6.178 | 3.178 | 9.232 | 1.563 |

| Heritage sampling points | CuO | PbO | BaO | $P_2O_5$ | SrO | $SnO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|---|
| 07 | 5.526 | 0.447 | 0.650 | 3.318 | 0.045 | 0.214 | 0.110 |
| 09 | 2.536 | 0.429 | 0.623 | 1.826 | 0.043 | 0.205 | 0.106 |
| 10 | 1.384 | 0.432 | 0.628 | 0.000 | 0.044 | 0.206 | 0.107 |
| 12 | 2.517 | 0.400 | 0.581 | 0.730 | 0.040 | 0.191 | 0.099 |
| 22 | 0.773 | 0.368 | 0.536 | 0.941 | 0.037 | 0.176 | 0.091 |
| 27 | 2.593 | 0.441 | 0.642 | 1.934 | 0.045 | 0.211 | 0.109 |

**Table 6.** Prediction of chemical composition of lead barium glass

| Heritage sampling points | $SiO_2$ | $Na_2O$ | $K_2O$ | CaO | MgO | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| 02 | 66.796 | 0.000 | 1.425 | 0.914 | 0.943 | 7.946 | 2.026 |
| 08 | 49.719 | 0.000 | 0.000 | 0.775 | 0.000 | 2.492 | 0.000 |
| 08 Severe weathering point | 18.288 | 0.000 | 0.000 | 2.684 | 0.000 | 3.317 | 0.000 |
| 11 | 65.410 | 0.000 | 0.301 | 1.449 | 0.600 | 3.945 | 0.000 |
| 26 | 49.278 | 0.000 | 0.000 | 0.760 | 0.000 | 1.313 | 0.000 |
| 26 Severe weathering point | 14.772 | 0.000 | 1.171 | 2.535 | 0.000 | 3.529 | 0.000 |
| 34 | 68.000 | 0.000 | 0.350 | 0.314 | 0.000 | 2.319 | 0.528 |
| 36 | 63.220 | 11.726 | 0.165 | 0.125 | 0.000 | 1.925 | 0.302 |

ISSN: 2688-8645

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|---|---|---|---|---|---|---|---|
| 38 | 60.301 | 8.355 | 0.000 | 0.264 | 0.000 | 3.545 | 0.314 |
| 39 | 60.468 | 0.000 | 0.000 | 0.542 | 0.000 | 0.868 | 0.000 |
| 41 | 45.521 | 0.000 | 0.800 | 2.594 | 2.921 | 6.185 | 2.611 |
| 43 point 1 | 35.725 | 0.000 | 0.000 | 3.199 | 1.116 | 4.879 | 1.294 |
| 43 point 2 | 53.471 | 0.000 | 0.000 | 3.344 | 1.016 | 6.329 | 2.026 |
| 49 | 58.948 | 0.000 | 0.000 | 1.989 | 1.306 | 8.297 | 3.319 |
| 50 | 45.796 | 0.000 | 0.000 | 1.723 | 0.519 | 3.587 | 0.497 |
| 51 point 1 | 53.760 | 0.000 | 0.000 | 1.658 | 1.128 | 8.638 | 1.538 |
| 51 point 2 | 52.412 | 0.000 | 0.000 | 2.670 | 1.544 | 4.641 | 0.610 |
| 52 | 53.491 | 8.382 | 0.000 | 1.000 | 0.496 | 1.816 | 0.283 |
| 54 | 52.954 | 0.000 | 0.561 | 1.608 | 1.320 | 7.429 | 0.000 |
| 54 Severe weathering point | 47.444 | 0.000 | 0.000 | 0.000 | 1.335 | 7.623 | 0.000 |
| 56 | 59.844 | 0.000 | 0.000 | 0.527 | 0.000 | 2.861 | 0.000 |
| 57 | 54.981 | 0.000 | 0.000 | 0.601 | 0.000 | 3.551 | 0.000 |
| Heritage sampling points | CuO | PbO | BaO | $P_2O_5$ | SrO | $SnO_2$ | $SO_2$ |
| 02 | 0.126 | 19.064 | 0.000 | 0.560 | 0.093 | 0.000 | 0.000 |
| 08 | 6.634 | 15.457 | 23.475 | 0.756 | 0.244 | 0.000 | 0.270 |
| 08 Severe weathering point | 3.215 | 28.106 | 36.986 | 2.557 | 0.561 | 0.000 | 2.530 |
| 11 | 2.478 | 10.794 | 8.663 | 1.558 | 0.192 | 0.000 | 0.000 |
| 26 | 6.794 | 16.053 | 24.452 | 0.665 | 0.299 | 0.000 | 0.207 |
| 26 Severe weathering point | 3.690 | 25.938 | 42.865 | 2.045 | 0.657 | 0.000 | 2.687 |
| 34 | 0.740 | 19.314 | 5.787 | 0.055 | 0.116 | 0.000 | 0.000 |
| 36 | 0.280 | 14.513 | 5.269 | 0.100 | 0.094 | 0.000 | 0.000 |
| 38 | 0.345 | 19.712 | 5.459 | 0.0750 | 0.200 | 0.000 | 0.000 |
| 39 | 0.523 | 30.691 | 5.064 | 0.229 | 0.375 | 0.000 | 0.000 |
| 41 | 0.121 | 0.121 | 7.328 | 1.569 | 0.309 | 0.000 | 0.000 |
| 43 point 1 | 3.976 | 37.614 | 6.390 | 0.000 | 0.492 | 0.000 | 0.000 |
| 43 point 2 | 0.960 | 24.073 | 2.446 | 2.696 | 0.309 | 0.000 | 0.000 |
| 49 | 0.370 | 15.278 | 3.803 | 1.938 | 0.251 | 0.000 | 0.000 |
| 50 | 0.743 | 24.466 | 11.013 | 1.377 | 0.449 | 0.000 | 0.000 |
| 51 point 1 | 0.773 | 19.190 | 5.947 | 1.509 | 0.227 | 0.962 | 0.000 |
| 51 point 2 | 0.475 | 27.515 | 0.000 | 1.832 | 0.000 | 0.000 | 0.000 |
| 52 | 0.375 | 21.513 | 5.467 | 1.012 | 0.244 | 0.000 | 0.000 |
| 54 | 0.509 | 28.777 | 5.095 | 0.859 | 0.558 | 0.000 | 0.000 |
| 54 Severe weathering point | 0.959 | 35.389 | 0.000 | 3.341 | 0.829 | 0.000 | 0.000 |
| 56 | 0.419 | 18.488 | 9.658 | 0.445 | 0.000 | 0.000 | 0.000 |
| 57 | 0.648 | 21.295 | 11.394 | 0.000 | 0.000 | 0.000 | 0.000 |

ISSN: 2688-8645

## 4. Conclusion

With a long time of burial, ancient glass is very easy to be weathered in this process, and its composition is extremely easy to change, which will affect the identification of glass cultural relics. Therefore, this paper tries to solve the problem of composition analysis of ancient glass products by using mathematical model. The correlation analysis of chemical composition of high potassium and lead barium glasses was analyzed. In addition, the composition of glass relics before weathering is predicted. This paper provides some research basis for the analysis of the composition of glass before weathering.

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