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Experimental Archaeology Project Determining the Effects of High Heat on Ceramics from Market Street Chinatown

Background

Market Street Chinatown was founded in San Jose in the 1860s and flourished until its destruction by arson fire in 1887. It was not until the construction of the Fairmont Hotel, which is located in now downtown San Jose, in the 1980s that the archaeological site and the community began to be studied. In 1985 and 1986 the San Jose Redevelopment Agency sponsored archaeological excavations by Archaeological Resource Services during the initial construction phases. Full analysis of the artifacts recovered from the site was never done at this time, and it was not until the collection was transferred to Stanford University in 2003 that a concerted effort was made to catalogue and analyze the collection.

More recently, we have become interested in evaluating the extent and the effects of the arson fire that destroyed the Market Street site in 1887. Given the relatively fragmentary nature of the original excavation records, our understanding of the fire relies heavily on the artifacts recovered from burned contexts from the site. We have since begun preliminary analyses of the burned ceramics from the site, documenting the wares, types, as well as the presence or absence of indicators of burning or high heat. It is this last issue that has been of particular concern to this analysis of the burned artifacts, as we do not clearly understand the effects of high heat on specific paste, temper, and glaze types at this time. Additionally, we are trying to determine if these heat-affected artifacts were damaged during the 1887 fire, or if they were burned during trash disposal or other daily activities. To date, we have not been able to find reliable forensic literature or previous archaeological studies that address these concerns, and the idiosyncratic nature of 19th century ceramics make it difficult to make productive comparisons between these and contemporary ceramics.

In order to better understand the possible impacts of high heat exposure to the ceramics, we wish to initiate a preliminary experimental project aimed at better understanding the impacts of high heat to different glazes, tempers, and paste types. Experimental archaeology is useful for setting up an artificial system in which one can study a specific set of processes through the control of relevant variables which aids in our understanding of various processes that result in the way in which the archaeological record looks to us today (Schiffer et al. 1998). Ceramic materials can suffer a wide range of damage in response to the stresses created by changes in temperature and temperature gradients. While many studies have been conducted on the thermodynamic properties of different prehistoric ware and temper types (Brontisky and Hamer 1986, Tite 1999, Young and Stone 1990), we are unaware of pre-existing studies of the impacts of heat on 19th century British wares and Asian porcelains and stonewares. Given the lack of experimental studies detailing the impact of heat on these ceramic types, we feel that a basic study detailing the effects of varying levels of heat on the ceramics from the Market Street site would be useful not only for this analysis, but also provide a useful set of results for future analyses.

Methods for Heating

We have used a small sample of four basic ceramic types, Asian Stoneware, Four Seasons, and Blue Underglaze Porcelain (Bamboo), and White Improved

Earthenware that were recovered from the Market Street site. I have done the pre and post firing analysis on the Asian Porcelains. Asian Porcelain is a high fire ceramic (2500 F) and is glazed and decorated with a colored overglaze. We have used ceramic fragments from Feature "0" from the collection, which are unprovenienced and thus have no potential research value. We then broke each ceramic type into twenty-one 3-4-gram pieces in order to subject each fragment to various levels of heat for varying periods of time. We have used a Thermolyne ceramic oven in which to heat the ceramics. Although an oven provides an artificial environment for burning ceramics, it provides a more controlled setting while allowing us to control exact temperatures and times that would not be as easily possible in an outdoor firing pit. After reserving one fragment as a control, each smaller ceramic sherd was subjected to varying temperatures for varying durations of time.

Each of the sherds was placed on a ceramic tray in a Thermolyne oven when cool and then fired for the specified duration of time once the oven had come up to temperature. We then let the oven cool completely before opening/removing the sherds in order to prevent any potential damage to the sherds when hot. We heated each of the ware types to 815, 954, and 1093 degrees Celsius for .5 and 2 hours at each temperature in order to gauge the effects of both temperature and time on each of the different wares. Since in normal firing the duration, temperature, and atmosphere are the three primary variables, we deduced that these three variables would also be the primary determinates of change in a post-firing burning scenario. We have chosen the above temperatures because an open fire burns at 900 C close to the base and the average house fire burns at 1000 C. We wished to bracket these two temperatures in order to determine possible effects of heat on both the low and high end of the spectrum from an open flame to a more intense house fire. If the two ends of the heat spectrum produce noticeably different results, then we may be able to more closely approximate in what type of setting the ceramics from Market Street were burned. One possible drawback to these temperatures is that they may affect the glaze only, since the firing temperatures for porcelains, stonewares, and eathernwares are higher than those temperatures we used in the experiment (Figure 1).

Methods for Analysis

We analyzed each of the sherds pre and post burning in order to determine morphological changes to paste, temper, and glaze that may have occurred due to heat exposure (See Analysis Form, Figure 2). We recorded the weights (grams), maximum lengths and maximum widths (cm) of each sherd pre and post firing using an electronic scale and a pair of electronic calipers. We also used a Munsell Color Chart in order to record the glaze colors, decoration colors, and the paste colors of each of the sherds before and after firing. Lastly, using Mohe's hardness scale, we recorded the hardness of the paste before and after firing. Finally, we wished to understand possible changes to glazes on each of the ceramics and thus recorded the presence or absence of morphological changes, such as bubbling and cracking. These changes were discerned with the aide of microscopic analysis.

Results

The results of this experiment are shown in Figures 3, 4, and 5. These tables summarize changes in paste color and hardness, as well as visually observed color changes to the glazes. The tables are followed by microscopic images illustrating some of the more significant changes to the color and consistency of the glazes observed post heat treatment.

Discussion

There were a few changes to the lengths and thicknesses of each of the sherds post burning, although these differences almost certainly come from user error and our indiscrimination as to exactly where we measured each sherd before and after each trial. Thus, the differences we see in the shapes and sizes of the sherds are most likely arbitrary. The weight of the sherds also remained constant. This is surprising given the non-organic content of the paste and temper and given that any water or moisture would have been lost in the clay after the initial firing (Figure 3).

The most consistent indicator of heat treatment through analysis of paste is hardness. In every case, the hardness of the porcelain paste increased by 1 on Moh's hardness scale (Figure 4). It is also noteworthy that it is impossible to determine differences in temperature and duration alone due to the high hardness of both the untreated and treated samples. Since the Moh scale does not exceed 9, it is impossible at this stage to determine whether or not temperature or duration has the most affect on hardness. Increases in paste hardness are a somewhat surprising finding given the high firing temperature of modern porcelain material (Pottery

Making Illustrated 2005). Given that the initial firing temperature of modern porcelain is between 1300 and 1400 degrees Celsius, it seems plausible that we would see no changes in the overall hardness of the paste given that our firing temperatures in this experiment were significantly lower.

Color changes to the paste and the glazes were also noted (Figure 5). In all of the samples, the paste post-firing turned to a deep orange color, indicating the possible presence of iron in the paste which became oxidized once it was fired. Further studies can be conducted in order to determine the mineral content of the porcelain paste and can help us to determine whether or not these materials oxidize at high temperatures. Changes in the colors of the glazes and decoration were also noted in some cases, although color changes seemed to be highly idiosyncratic and did not appear to be correlated with temperature or duration specifically.

Microscopic Analysis

Bubbling of the glaze surface, as well as color changes, seem to be consistent and predictable indicators of some degree of heat treatment (Figure 5). In the case of the Bamboo ware, small bubbles in the glaze could be seen in the unfired control sample. Post heat treatment, the bubbles appear to have become more numerous, although the bubbles themselves did not appear to become larger with the application of heat. Although all of the Bamboo wares showed evidence of bubbling, there were no noticeable differences in bubbling patterns at the different temperatures and durations. Additionally, there were color changes to most of the heat-treated Bamboo ware samples, although differentiation in color is not correlated with either temperature or duration. The differences in color change may be correlated with differences in the chemical composition of the glazes, rather than differences in temperature or duration.

In the case of the Four Seasons wares, bubbling of the glaze surface seems to be more consistent with temperature and duration. The sherd that was heated to 1093 degrees for 2 hours shows a greater degree of surface bubbling that the sherds that were heated for shorter durations. An interesting phenomenon is that as there is a direct correlation between temperature and duration and the intensity of bubbling on the decoration. The sample that was heated for 1093 degrees for two hours exhibits intense bubbling to the point where some of the enamel decoration appears to have partially dissipated. The Four Seasons wares are decorated post-firing with a series of lead based enamel floral motifs. In all of the cases, the designs suffered from either cracking or bubbling or both. It is possible that the lead/glass mixture used for decoration is less able to withstand higher heat than the glazes.

Discussion

This study offers a useful analysis for understanding the Market Street Chinatown archaeological assemblage, as well as providing a platform for other historical archaeological projects interested in forensic analyses of heat affected ceramics. The results of this study indicate that increased hardness and morphological changes to the glazes are the most promising indicators of high heat. The glazes on the Four Seasons ware exhibit levels of melting and bubbling consistent with the time and duration of heat.

In order for this preliminary study to become more applicable to a wider variety of studies, it may be useful to gain a better understanding of the chemical compositions to the glazes on the two ware types in order to better analyze the effects of high heat on them. Glazes are a particular kind of non-crystalline glass, which are used as a coating melted or fused onto a ceramic body (Rice 1987;98). Glazes are either classified as high temperature or low temperature depending on whether they are fired below 1150-1200 C or above 1200-1250 C. Since we do not know what kind of glaze was used on the mid 19th century commercially manufactured Asian porcelains, we were not able to anticipate how the glazes would have responded to high heat. In all of the cases, the glaze formed small bubbles both on the underglazes and the decorative overglazes. Given that the temperatures in our experiment did not exceed 1200 degrees C and provided that all of the ceramic glazes suffered from morphological changes after firing, we tentatively suggest that the glazes on the Asian porcelains were low temperature glazes.

We tentatively suggest that Asian porcelains can be used a reliable indicators of heat exposure, due to noticeable changes in their paste and glaze characteristics, but that due to the inconsistency in changes across differing temperatures and duration, they are not particularly useful for determining that context of heat application. Future experimental studies would be useful in supplementing this preliminary analysis. For example, it would be useful to burn the sherds in a open pit firing in order to more closely replicate the conditions of the Market Street Chinatown arson fire as well as the conditions of a trash-burning scenario. Because the oven does not allow for external flows of air, thus creating a reduced oxygen environment, it may be the case that some of the color changes seen on the Market

Street heat affected artifacts are due to an oxidized/open air fire. Additionally, more trials involving longer durations and lower and higher temperatures may yield different and productive results.

We hope that this experiment will not only help us understand the nature of the fire(s) at Market Street Chinatown and the effects on the artifacts, but will also provide future researchers with the tools to analyze ceramics from other collections and build upon this research to conduct further useful experiments.

References

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Figures

Figure 1.

KILN FIRING CHART

Firing converts ceramic work from weak greenware into a strong, durable form. As the temperature in a kiln rises, many changes take place in the clay; and understanding what happens during the firing can help you avoid problems. The following chart provides highlights of what happens when firing clay.

Temperature C°	Temperature F°	Color	Cone (approx.)	Event
1400	2552	Brilliant white	14	End of porcelain range
			13	
			12	
1300	2372	White	11	End of stoneware range
			9	
		Yellow-white	7	
1200	2192		5½	End of earthenware (red clay) range
		Yellow	4	
			2	Between 1100-1200°C, mullite and cristobalite (two types of silica) form when clay starts converting to glass. Clay and ceramic particles start to melt together and form crystals. These changes make the material shrink as it becomes more dense. Soaking (holding the end temperature) increases the amount of fused matter and the amount of chemical action between the fluxes and the more refractory materials.
1100	2012	Yellow-orange	1	
			04	
		Orange	05	
1000	1832		06	
			07	
		Red-orange	08	

Figure 2.

Ceramic Analysis Form

MSC Ceramic Firing Experiment

Name: Date:

Catalog Number:

Ware Type:

Decorative motif:

Temperature:

Duration:

Pre-Firing Attributes

Paste

Hardness (Mohe scale):

Color (Munsell):

Glaze Attributes

Color (Munsell):

Crackling (check)	Yes:	No:
Bubbles (check)	Yes:	No:
Flaking (check)	Yes:	No:
Spalling (check)	Yes:	No:

Decoration (Overglaze)

Color (Munsell):

Crackling (check)	Yes:	No:
Bubbles (check)	Yes:	No:
Flaking (check)	Yes:	No:
Spalling (check)	Yes:	No:

Weight (g):

Maximum Length/Thickness (cm):

Post-Firing Attributes

Paste

Hardness (Mohe scale):

Color (Munsell):

Fire-clouding present (check)	Yes:	No:

Glaze Attributes

Color (Munsell):

Crackling (check)	Yes:	No:
Bubbles (check)	Yes:	No:
Flaking (check)	Yes:	No:
Spalling (check)	Yes:	No:

Decoration (Overglaze)

Color (Munsell):

Crackling (check)	Yes:	No:
Bubbles (check)	Yes:	No:
Flaking (check)	Yes:	No:
Spalling (check)	Yes:	No:

Weight (g)

Maximum Length/Thickness (cm)

Figure 3

Temperature (F)	Duration (hr)	Ware Type	Decoration	Pre-Fire Weight (g)	Post-Fire Weight (g)	Pre-Fire Thickness (cm)	Post-Fire Thickness (cm)	Pre-Fire Length (cm)	Post-Fire Length (cm)
1093	0.5	Asian Porcelain	Bamboo	2	2	0.39	0.43	2.4	2.38
1093	0.5	Asian Porcelain	Four Seasons	3	3	0.31	0.31	3.4	3.4
1093	2	Asian Porcelain	Bamboo	3	3	0.34	0.34	3.28	3.28
1093	2	Asian Porcelain	Four Seasons	3	3	0.24	0.24	3.92	3.97
815	0.5	Asian Porcelain	Bamboo	3	2	0.49	0.49	2.39	2.38
815	0.5	Asian Porcelain	Four Seasons	3	3	0.36	0.38	3.41	3.41
815	2	Asian Porcelain	Bamboo	3	3	0.49	0.49	2.78	2.78
815	2	Asian Porcelain	Four Seasons	4	4	0.45	0.43	3.52	3.49
954	2	Asian Porcelain	Bamboo	4	4	0.69	0.7	2.69	2.7
954	2	Asian Porcelain	Four Seasons	3	3	0.35	0.35	3.5	3.5
954	0.5	Asian Porcelain	Bamboo	3	3	0.3	0.32	3.14	3.14
954	0.5	Asian Porcelain	Four Seasons	3	3	0.42	0.45	2.92	2.86

Figure 4.

Change in Hardness (Mohe Scale)

Temperature (C)	Duration (hr)	Ware Type	Decoration	Difference in Hardness
1093	0.5	Asian Porcelain	Bamboo	(+)1
1093	0.5	Asian Porcelain	Four Seasons	(+)1
1093	2	Asian Porcelain	Bamboo	(+)1
1093	2	Asian Porcelain	Four Seasons	(+)1
815	0.5	Asian Porcelain	Bamboo	(+)1
815	0.5	Asian Porcelain	Four Seasons	(+)1
815	2	Asian Porcelain	Bamboo	(+)1
815	2	Asian Porcelain	Four Seasons	(+)1
954	2	Asian Porcelain	Bamboo	(+)1
954	2	Asian Porcelain	Four Seasons	(+)1
954	0.5	Asian Porcelain	Bamboo	(+)1
954	0.5	Asian Porcelain	Four Seasons	(+)1

Figure 5.

Changes in Color

Temperature (F)	Duration (hr)	Ware Type	Decoration	Munsell Paste Pre	Munsell Paste Post	Munsell Glaze Pre	Munsell Glaze Post	Munsell Decoration Pre	Munsell Decoration Post
1093	0.5	Asian Porcelain	Bamboo	GYG 8/5GY	5YR 6/4	GYG 7/10GY	GYG 8/10GY	7.5B 4/2	7.5B 4/2
1093	0.5	Asian Porcelain	Four Seasons	N9	5YR 6/4	BG-BP 8/10 BG	GYG 8/10 GY	5BG 3/6	10GY 5/6
1093	2	Asian Porcelain	Bamboo	GYG 8/5GY	5YR 6/4	GYG 7/10GY	GYG 8/5GY	7.5B 4/2	7.5 BG 4/2
1093	2	Asian Porcelain	Four Seasons	N9	5YR 7/4	BG-BP 8/10BG	BG-BP 8/10BG	5BG, 10RP 5/8	GYG 9/5GY, 7.5 GY 7/4
815	0.5	Asian Porcelain	Bamboo	GYG 8/5GY	5YR 6/4	GYG 7/10 GY	BG-BP 8/10BG	7.5B 4/2	7.5B 7/2
815	0.5	Asian Porcelain	Four Seasons	N9	5YR 6/4	BG-BP 8/10BG	BG-BP 8/10BG	5BG 3/6	2.5BG 4/6
815	2	Asian Porcelain	Bamboo	N9	5YR 6/5	RY 6/5Y	RY 6/5	10G 4/2	RY 4/10
815	2	Asian Porcelain	Four Seasons	N9	5YR 6/4	BG-BP 8/10BG	BG-BP 8/10BG	5BG 3/6, 10RP 5/8	5BG 3/6, 10RP 5/8
954	2	Asian Porcelain	Bamboo	GYG 8/5GY	7.5YR 5/6	GYG 7/10 GY	GYG 8/10 GY	5B 7/2	5B 7/2

954	2	Asian Porcelain	Four Seasons	N9	5YR 6/5	BG-BP 8/10 BG	GYG 8/10 GY	5BG 5/6, 10RP 5/8	2.5G 5/6
954	0.5	Asian Porcelain	Bamboo	GYG 8/5GY	7.5YR 5/6	RY 6/5Y	GYG 8/10 GY	5B 7/2	5B 7/2
954	0.5	Asian Porcelain	Four Seasons	N9	5YR 6/4	BG-BP 8/10BG	BG-BP 8/10BG	5BG 3/6	10GY 5/6

Figure 6.

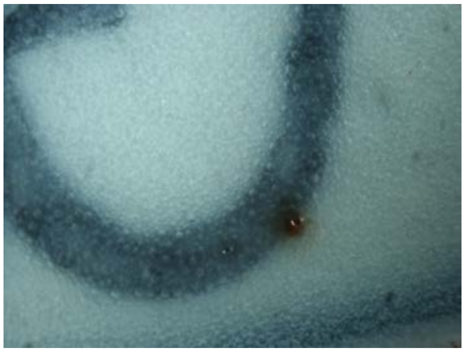
Surface Changes to Glaze

Temperature (C)	Duration (hr)	Ware Type	Decoration	Pre-Fire Bubbling	Post-Fire Bubbling
1093	0.5	Asian Porcelain	Bamboo	no	yes
1093	0.5	Asian Porcelain	Four Seasons	no	yes
1093	2	Asian Porcelain	Bamboo	no	yes
1093	2	Asian Porcelain	Four Seasons	no	yes
815	0.5	Asian Porcelain	Bamboo	no	yes
815	0.5	Asian Porcelain	Four Seasons	no	yes
815	2	Asian Porcelain	Bamboo	no	yes
815	2	Asian Porcelain	Four Seasons	no	yes
954	2	Asian Porcelain	Bamboo	no	yes
954	2	Asian Porcelain	Four Seasons	no	yes
954	0.5	Asian Porcelain	Bamboo	no	yes
954	0.5	Asian Porcelain	Four Seasons	no	yes

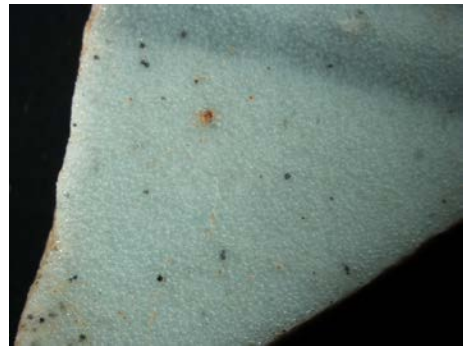
Surface Changes to Decoration (Overglaze and Enamel)

Temperature (F)	Duration (hr)	Ware Type	Decoration	Pre-Fire Bubbling	Post-Fire Bubbling	Pre-Fire Flaking	Pre-Fire Flaking
1093	0.5	Asian Porcelain	Bamboo	no	yes	no	no
1093	0.5	Asian Porcelain	Four Seasons	no	yes	yes	yes
1093	2	Asian Porcelain	Bamboo	no	yes	no	no
1093	2	Asian Porcelain	Four Seasons	no	yes	yes	yes
815	0.5	Asian Porcelain	Bamboo	no	yes	no	no
815	0.5	Asian Porcelain	Four Seasons	no	yes	yes	yes
815	2	Asian Porcelain	Bamboo	no	yes	no	no
815	2	Asian Porcelain	Four Seasons	no	yes	yes	yes
954	2	Asian Porcelain	Bamboo	no	yes	no	no
954	2	Asian Porcelain	Four Seasons	no	yes	no	yes
954	0.5	Asian Porcelain	Bamboo	no	yes	no	no
954	0.5	Asian Porcelain	Four Seasons	no	yes	yes	yes

Heat Treated and Non-Heat Treated Ceramic Samples:

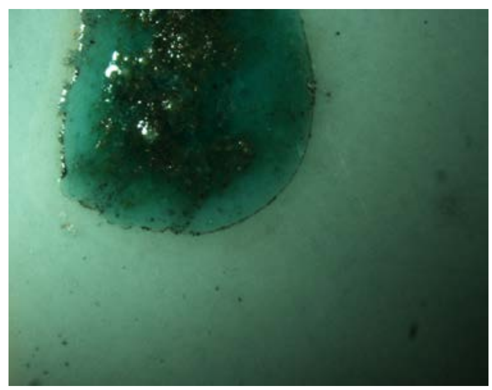


Bamboo Ware Unheated

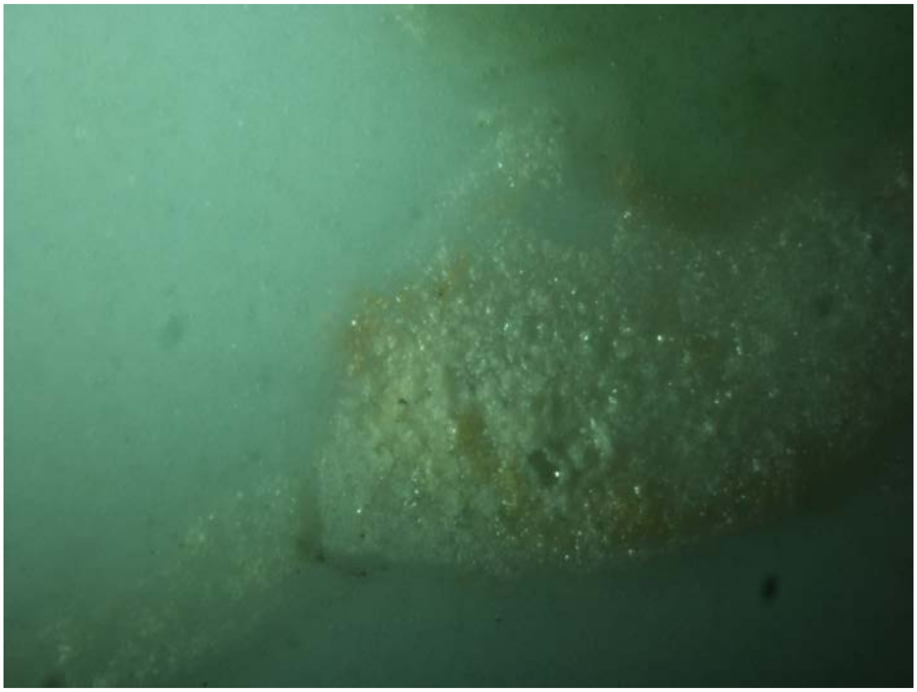


Bamboo Ware, 1093°, 2 hr

Four Seasons Ware Unheated



Four Seasons Ware 815°, 1/2 hr



Four Seasons Ware 1093°, 2 hr. Showing Bubbling/Dissipation of Enamel Decoration.