Glass Clay Body Flux

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GLASS CLAY BODY FLUX

FINAL REPORT

PREPARED FOR:

CWC
A division of the Pacific NorthWest Economic Region (PNWER)
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PROJECT CONSULTANTS:
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ACKNOWLEDGMENTS

CWC is a nonprofit organization providing recycling market development services to both businesses and governments, including tools and technologies to help manufacturers use recycled materials. CWC is an affiliate of the national Manufacturing Extension Partnership (MEP) – a program of the US Commerce Department's National Institute of Standards and Technology. The MEP is a growing nationwide network of extension services to help smaller US manufacturers improve their performance and become more competitive. CWC also acknowledges support from the US Environmental Protection Agency and other organizations.

Special thanks to Seattle Pottery Supply and Bruce Andersen for hard work above and beyond contract duties and to TriVitro for patience and material support.

1.0 INTRODUCTION

As early as the 1970's, the United States Department of the Interior, Bureau of Mines, became interested in the possibility of using glass as a flux for brick clays. The Bureau of Mines' studies concluded that "Substitution of glass for one-half of the clay in a red [brick clay] body reduced the firing temperature 500°F [from 2120°F to 1650°F], which [1] These studies took place following the first energy crisis in the United States, when the Department of the Interior was interested in reducing energy use by targeted industries.

Since the 1970's, additional unpublished proprietary data has been collected by several sources, and it is possible that a significant amount of glass is being used today as a clay body flux in proprietary processes. The CWC became interested in the potential of clay bodies as an alternative use for finely graded glass.

The action of vitrified material in a body has been described as follows:

> As the temperature of firing increases beyond red heat, other changes occur in the clay called vitrification. Vitrification is the hardening, tightening, and finally the partial glassification of clay. Vitrification gives to fired clay its characteristic hard, durable, dense, and rocklike properties. . . . Vitrification proceeds gradually, at first causing the clay to be rather loosely compacted and then, with the advance of temperature, causing it to become increasingly hard, up to the point of melting and deformation. The same clay can be either very soft or very dense, hard, and impervious, depending upon the temperature at which it is fired.[2]

The function of a body flux has been described as "The fluxes control the fusion or hardening point of the clay and make it fire to a satisfactory degree of density at whatever temperature is used."[3]

In January, 1998, Seattle Pottery Supply won a Technology Validation grant, funded by the United States National Institute for Standards and Technology (NIST), managed by

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[1] Tyrrell, M. E., and Goode, Alan H., "Waste Glass as a Flux for Brick Clays," United States Department of the Interior, Bureau of Mines, Report of Investigation 7701, 1972.
[2] Rhodes, Daniel, *Clay and Glazes for the Potter*, Chilton Book Company, 1973, page 17.
[3] Ibid, page 26.

the CWC. The purpose of the project was to develop some public information on the function of recycled glass as a body flux in clay bodies.

1.1 Soda-lime Glass

More than 95% of all manufactured glass is made from sodium oxide, calcium oxide, and silicon dioxide, commonly referred to as a soda-lime-silica composition. A typical average chemical content of the oxides in container and window glass is given by the following:

OXIDE	PERCENTAGE BY WEIGHT
SiO_2	72.8
Na_2O	13.7
CaO	8.8
MgO	4.0
Al_2O_3	.1
Fe_2O_3	.12
K_2O	.04
SO_3	.26

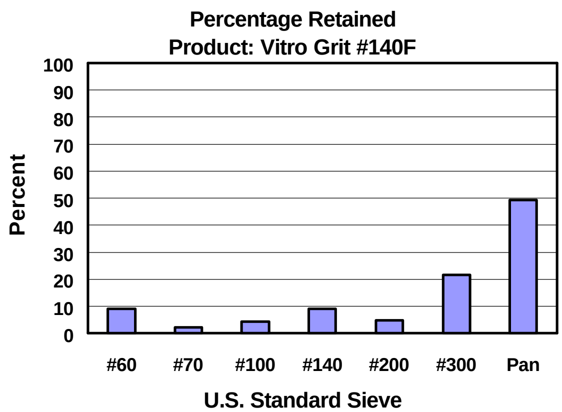
The facts that **soda lime glass is already a vitreous silicate, that vitreous silicates are generated during the maturation of clay bodies, and that vitreous silicates act as fluxes, reducing clay body maturation temperatures,** were strong evidence that the addition of soda lime glass to clay body raw materials could increase the efficiency of clay body firing and therefore be a value-added application for recycled glass fines.

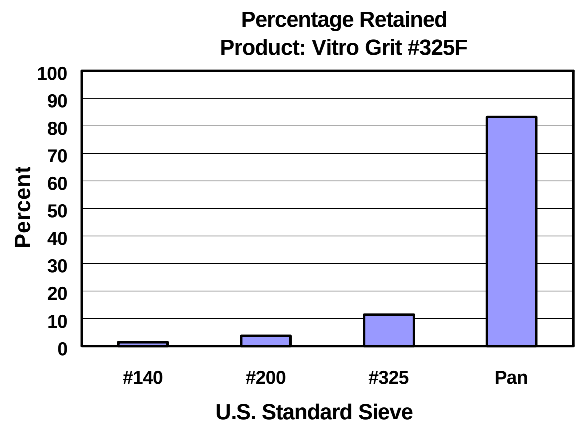
Glass for this project was furnished by TriVitro Corporation of Kent, Washington. TriVitro manufactures a variety of crushed glass products from post-consumer and post-industrial glass. Included in TriVitro's product line are abrasives (Vitro-Grit™), fusable glass (Vitro-Hue™) and filtration media (Vitro-Clean™). TriVitro furnished two grades of fine glass for this project, their grades 140F and 325F. Gradation analyses are shown in Figure 1. Except where noted, the best batches in this project were made using the 325F grade TriVitro glass.

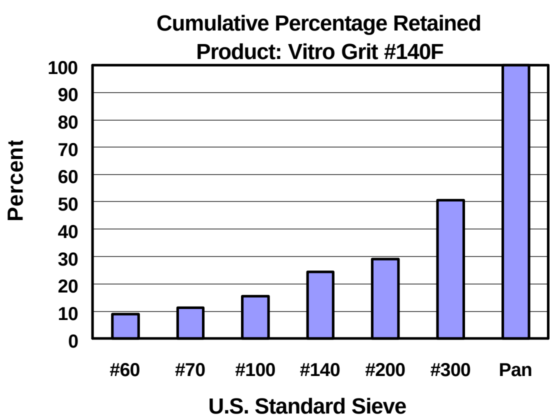
Figure 1 Sieve Analysis Histogram/VitroGrit #140F and #325F

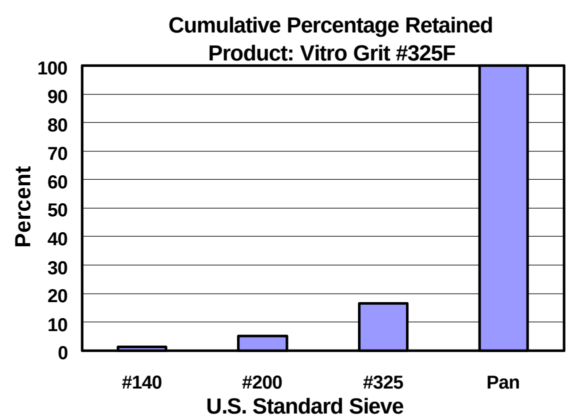
U.S. Std. Sieve	% Retained	Cum. % Retained	Cum. % Passing
#60	9.0	9.0	91.0
#70	2.1	11.2	88.8
#100	4.3	15.5	84.5
#140	9.0	24.5	75.5
#200	4.7	29.2	70.8
#325	21.5	50.6	49.4
Pan	49.4	100	

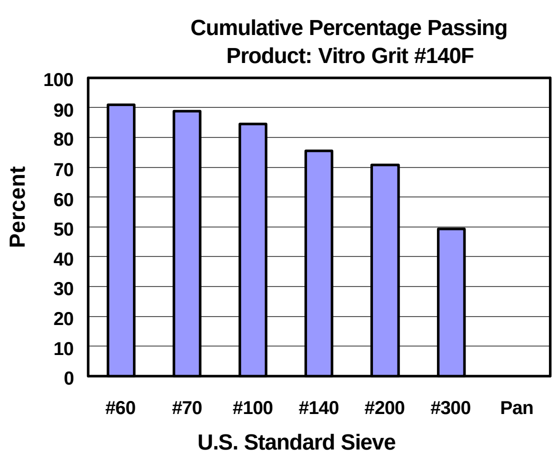
U.S. Std. Sieve	% Retained	Cum. % Retained	Cum. % Passing
#140	1.4	1.4	98.6
#200	3.8	5.2	94.8
#325	11.4	16.6	83.4
Pan	83.4	100	

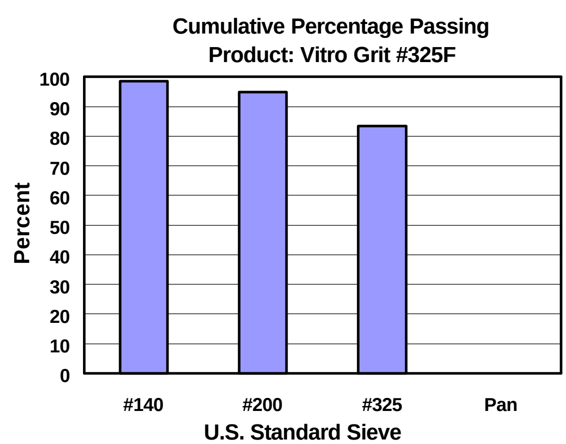












1.2 Recipes

Six standard clay mixes sold by Seattle Pottery Supply were chosen for experimentation. The clay recipes were for multi-purpose clay bodies. They were chosen to represent a variety of firing temperatures and uses.

The mixes were designated:

- Δ06 Red
- Δ06 White
- Δ6 Red
- Δ6 White
- Δ06 Casting Slip

The symbol "Δ06" represents "pyrometric cone 06," or just Cone 06. The cone rating designates the firing temperature expected for the clay mixture to reach maturity during firing. The following temperatures correspond to the end points of the cones used in this project, when heated at 36°F per hour:[4]

- Δ06 = 1841 °F
- Δ04 = 1922 °F
- Δ1 = 2057 °F
- Δ6 = 2174 °F

The constituents of the standard mixes were as follows:

[4] Ibid, page 315.

Weight		Weight percent	Ingredient

Recipe Name: Δ06 Red

7.5	gm	55.0	Red Art Fireclay
3.75	gm	27.5	Old Mine 4 Ball Clay (OM-4)
.06	gm	.4	Barium Carbonate
.13	gm	1.0	Bentonite Clay
.31	gm	2.2	Clay Grade Iron
1.88	gm	13.8	Talc
Material substituted for:			Talc

Recipe Name: Δ06 White

7.5	gm	46.0	Old Mine 4 Ball Clay (OM-4)
2.5	gm	15.3	Plastic Vitrox (PV) Ball Clay
.07	gm	.4	Bentonite Clay
6.25	gm	38.3	Talc
Material substituted for:			Talc

Recipe Name: Δ6 Red

6.25	gm	41.7	Lincoln Fireclay
5	gm	33.3	Newman Fireclay
1.25	gm	8.3	Old Mine 4 Ball Clay (OM-4)
.31	gm	2.1	Bentonite Clay
.31	gm	2.1	Clay Grade Iron
1.25	gm	8.3	Nepheline Syenite (Neph Sy)
.625	gm	4.2	Talc
Material substituted for:			Talc and neph sy

Recipe Name: Δ6 White

7.5	gm	52.1	Lincoln Fireclay
1.25	gm	8.7	Old Mine 4 Ball Clay (OM-4)
1.88	gm	13.1	EPK Kaolin
1.88	gm	13.1	30 mesh Sand
.44	gm	3.1	Ione 412 Porcelain Grog
.19	gm	1.3	Bentonite Clay
1.25	gm	8.7	Talc
Material substituted for:			Talc

Recipe Name: Δ06 Casting Slip

3783	gm	33	Old Mine 4 Ball Clay (OM-4)
3783	gm	33	SGP Ball Clay
3783	gm	33	Plastic Vitrox (PV) Ball Clay
.117	gm	ND	Barium Carbonate
.235	gm	ND	Soda Ash
1.6	oz.		Sodium Silicate
Material substituted for:			see Casting Slip section below

2.0 TESTS

Each of the clay bodies was mixed in a 35lb. capacity clay mixer for approximately 40 minutes. All of the ingredients were first mixed dry until uniform, then a measured amount of water was added. After the clay was thoroughly mixed, it was wedged, or de-aired.

Samples were made by rolling the clay into a flat slab 1cm. thick. Test samples were cut from this slab to 5cm wide by 30 cm long. On each piece a carefully measured 20cm mark was scribed and each one was marked for identification.

After drying, all samples were fired to the desired temperature (or cone) using a programmable kiln controller. After firing, shrinkage and absorption tests were performed.

- Shrinkage - after firing, the scribed 20cm mark was re-measured. The difference in length was calculated as the percent of shrinkage.

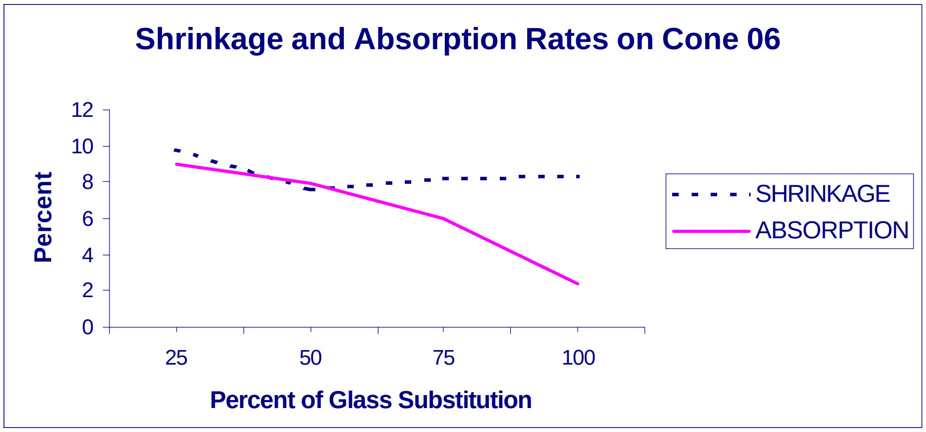
- Absorption -- after firing, each piece was weighed. After weighing, the pieces were soaked in water for 24 hours. When taken out they were patted down with a dry rag and weighed again. The difference in weight was calculated as the percentage of absorption.

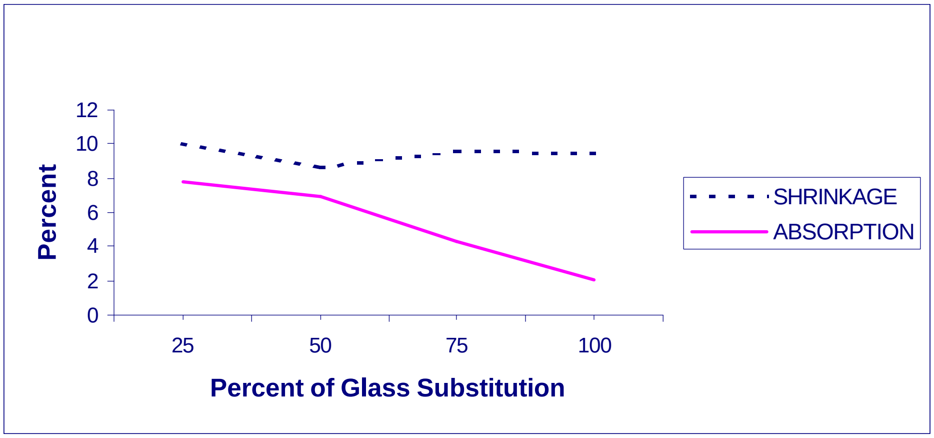
3.0 RESULTS

Graphical results and percentage substitutions are shown in Figures 2 through 7. Care must be taken in making assumptions or attempting to reproduce these results. Conducting these tests in potters' kilns is not an exact science. Mixing and firing properties of clays vary depending on many factors.

Figure 2 CONE 06 RED

INGREDIENTS	25%	50%	75%	100%
Red Art (Fireclay)	7.5	7.5	7.5	7.5
OM4	3.75	3.75	3.75	3.75
Barium Carbonate	0.06	0.06	0.06	0.06
Bentonite	0.13	0.13	0.13	0.13
Clay Grade Iron	0.31	0.31	0.31	0.31
Talc	1.41	0.94	0.47	0
Glass	0.47	0.94	1.41	1.88





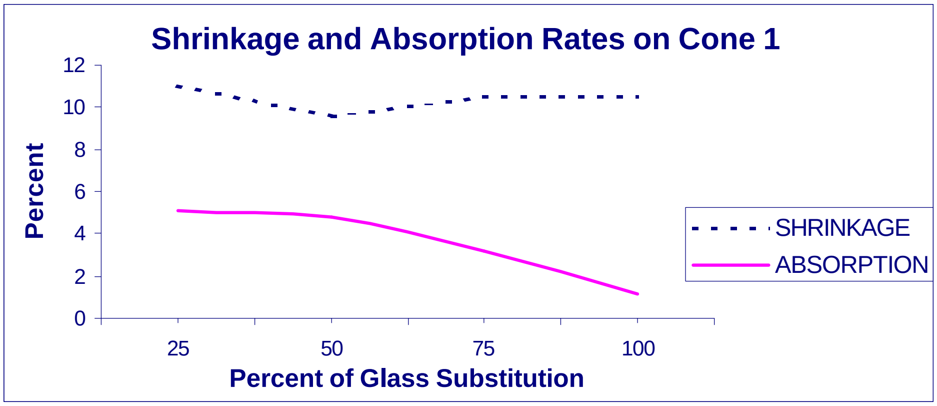
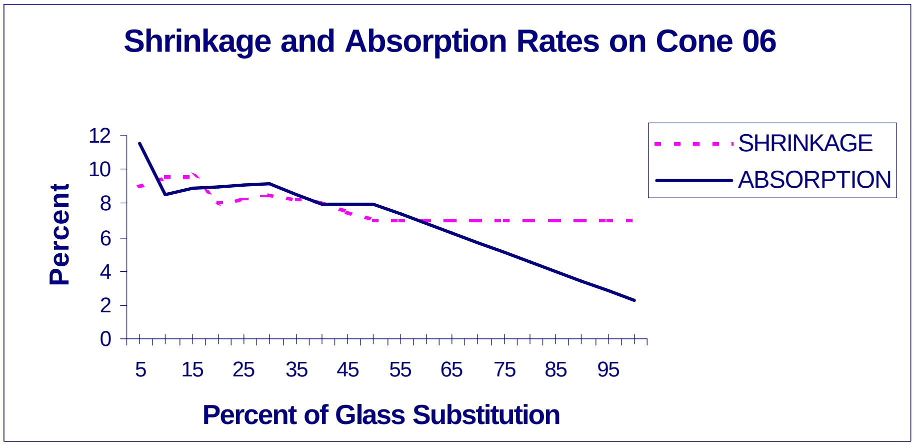
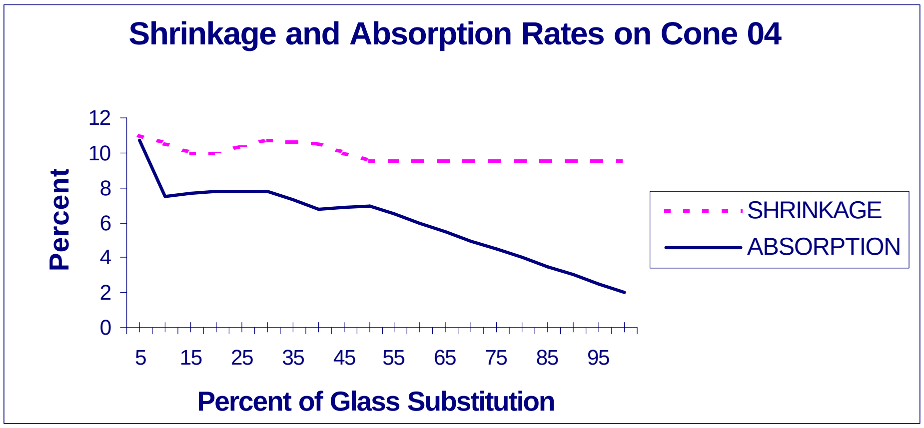


Figure 3   CONE 06 WHITE

INGREDIENTS	5%	10%	15%	20%	30%	40%	50%	100%
OM4 (Ballclay)	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
PV Clay	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Bentonite	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Talc	5.9375	5.625	5.3125	5.00	4.375	3.75	3.125	0
Glass	0.3125	0.625	0.9375	1.25	1.875	2.50	3.125	6.25





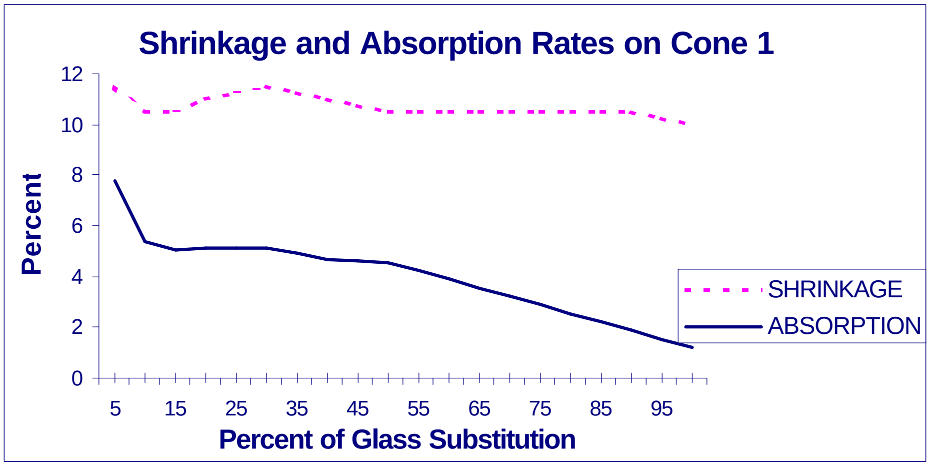
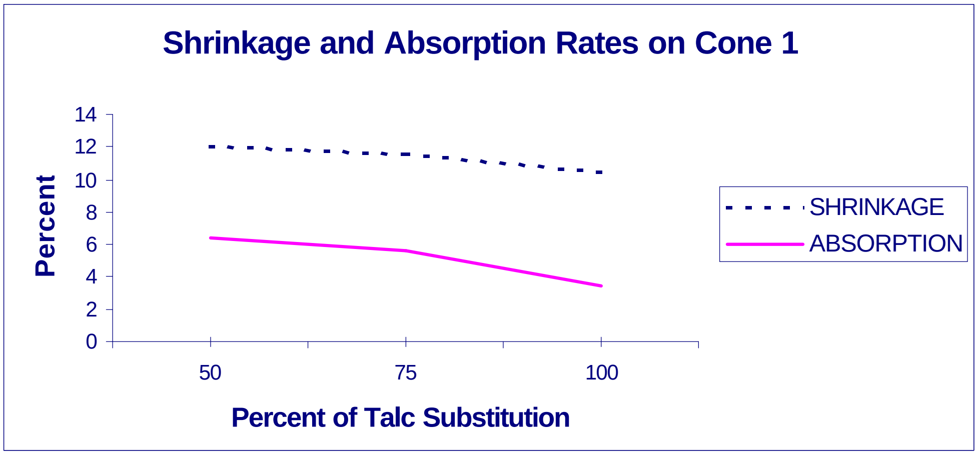
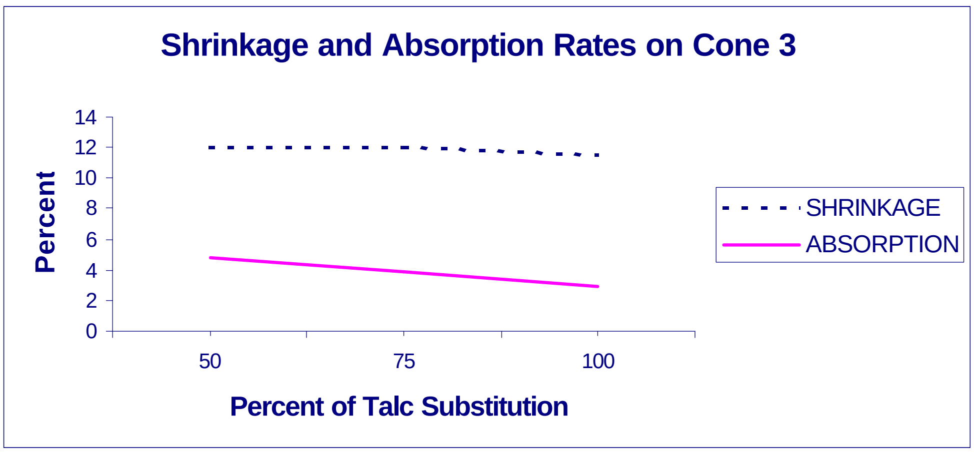


Figure 4 CONE 6 RED TALC SUBSTITUTION

INGREDIENTS	PERCENTAGE OF TALC		
	50%	75%	100%
Lincoln (Fireclay)	6.25	6.25	6.25
Newman (Fireclay)	5	5	5
OM4 (Ball Clay)	1.25	1.25	1.25
Bentonite	0.31	0.31	0.31
Iron (Clay Grade)	0.31	0.31	0.31
Neph Sy (Nepheline Syenite)	1.25	1.25	1.25
Talc	0.315	0.158	0
Glass	0.315	0.473	0.63





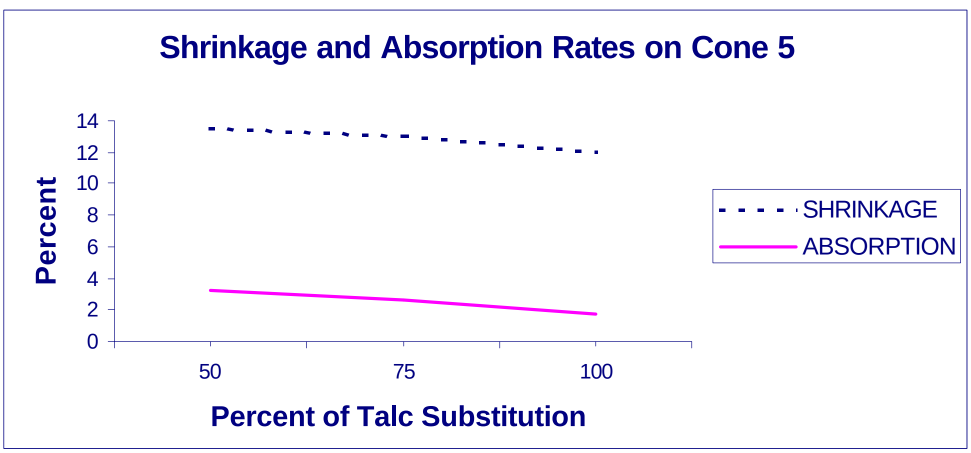
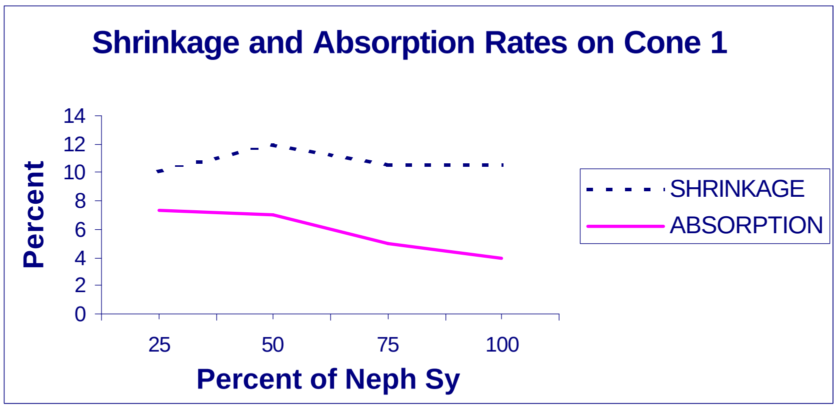
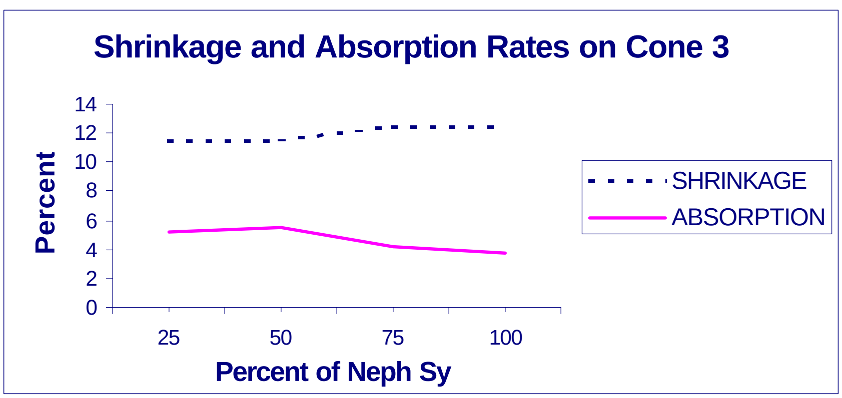


Figure 5

CONE 6 RED NEPH SY SUBSTITUTION

	PERCENT OF NEPH SY			
	25%	50%	75%	100%
Newman (Fireclay)				
Iron (Clay Grade)				
Neph Sy (Nepheline Syenite)				





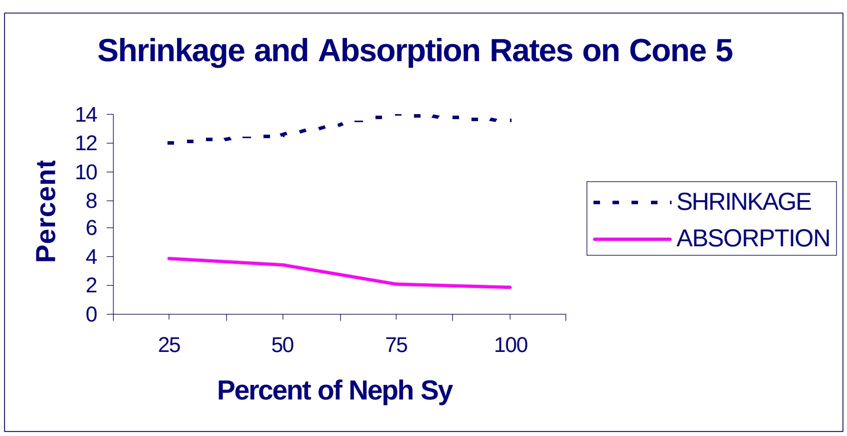
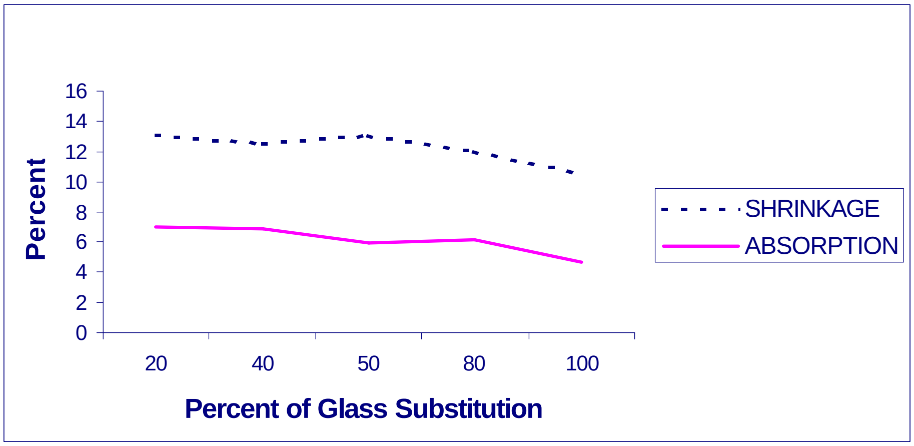
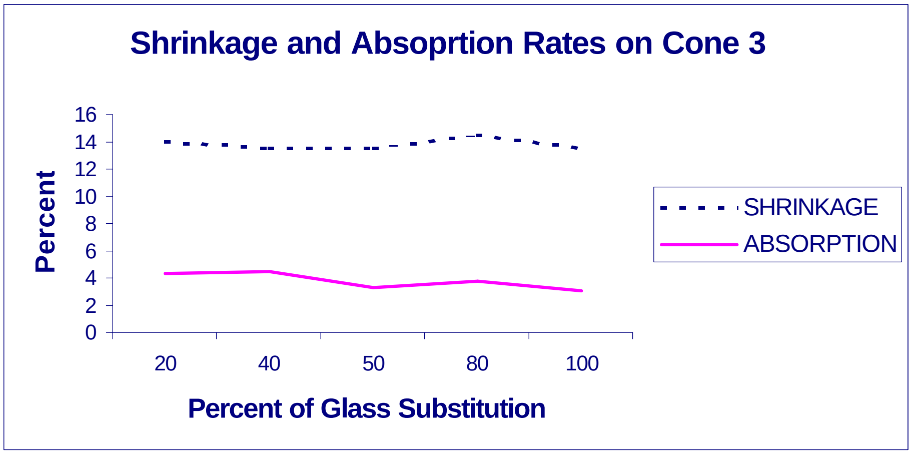


Figure 6 CONE 6 WHITE (GLASS)

INGREDIENTS	20%	40%	50%	80%	100%





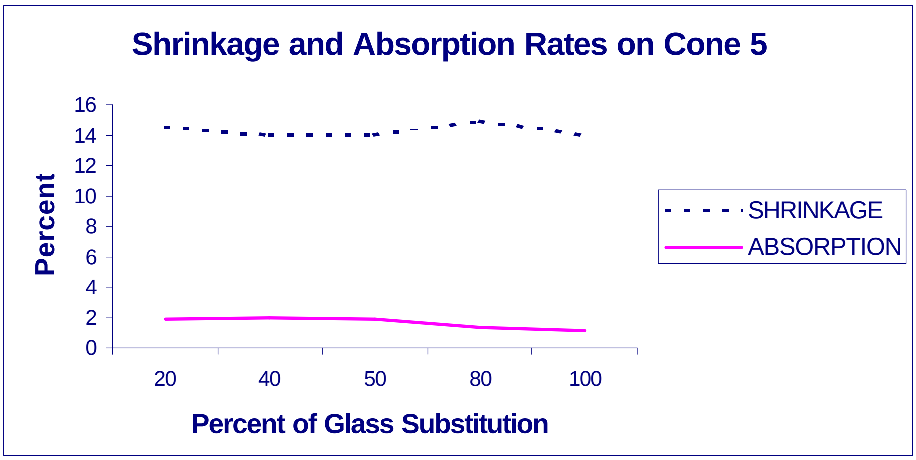
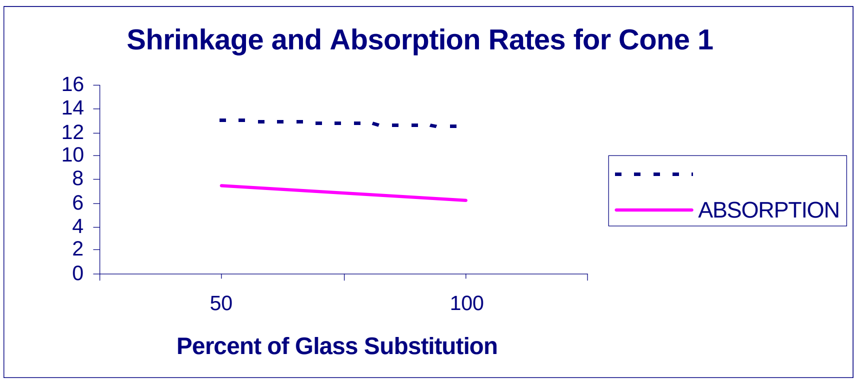
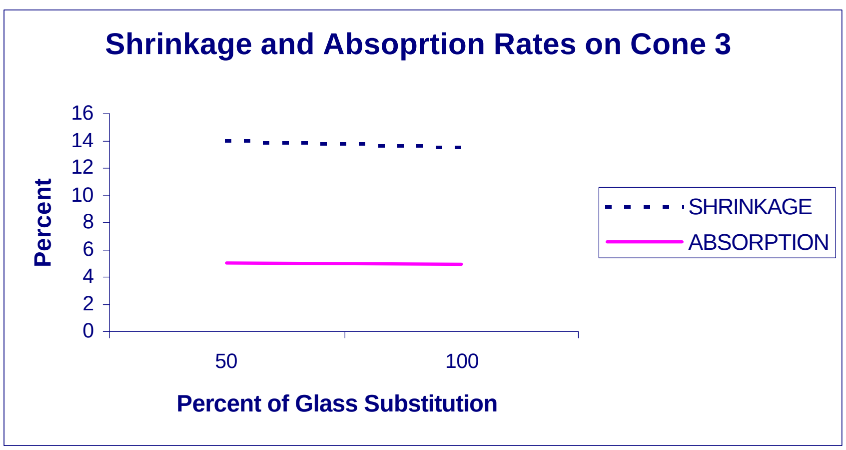


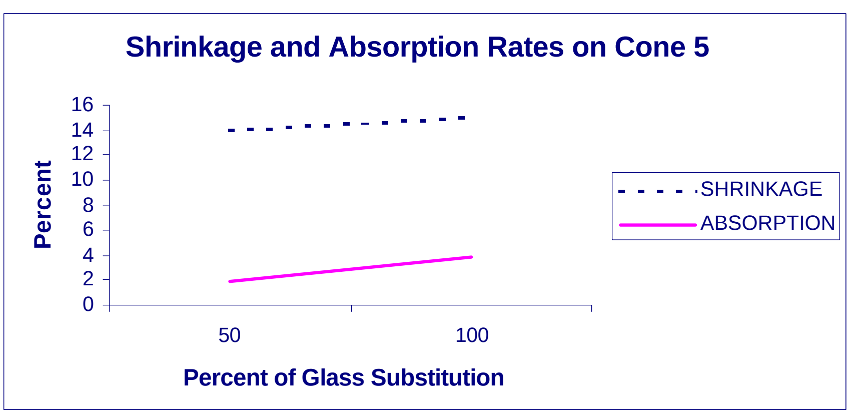
Figure 7

CONE 6 WHITE (140 GLASS)

	PERCENT OF GLASS	
	50%	100%







Two trends can be discerned from Figures 2 through 7. First, the line for shrinkage vs. percent substitution of glass is fairly flat. This means that the amount of shrinkage of the clay body was relatively unaffected by the glass substitution. In contrast, the line for absorption drops significantly with increasing percentages of glass. Lower absorption correlates to both increased strength and improved resistance to freeze/thaw cycles. Lower absorption is also indicative of lower temperature clay body maturation during firing.

In general, these results support the work of the Bureau of Mines cited above, to the effect that using glass as a clay body flux lowers the maturation temperatures of clay bodies.

Appendix A contains the raw data from the tests.

3.1 Problems with Clays

The major problem of all these clay bodies to a varying degree was solidification. After a very short time, a clay that was soft and malleable when mixed would stiffen to the point where it was unusable. This was particularly evident in clays with more than 20% glass substitution. Clays with high glass substitutions of 50% or more were very "short" or non-plastic. This made them unusable for most practical applications.

Probably the best application for any of these clay bodies would be press molding, which does not require a highly plastic clay body.

3.2 Slip Casting

Casting slips are clay mixtures made to be formed in plaster molds. Casting slips became one of the most interesting results of these tests. The high glass content slips were extremely vitrified at low temperatures. The surface of the castings were self-glazed, or took on a glass-like quality.

To keep the high amount of glass suspended, extra suspending agents (dispersants) were added. While the first casting was often successful, it would appear to leave scumming (most likely ball clay) on the surface of the mold. This would leave the mold unusable for subsequent castings.

The other problem with these slips was settling. Even with extra suspension agents, after a day or so, the glass would settle to the bottom of the mixture and solidify, making it practically impossible to remix even with a power mixer.

To experiment with casting slips, a basic ball clay mix was made of:

- 1 part OM-4 Ball Clay
- 1 part SGP Ball Clay
- 1 part Plastic Vitrox (PV) Ball Clay

Using this ball clay mix, the following experiments were performed. All tests were fired to Cone 06:

1) 12.5 lb. BALL CLAY MIX
   12.5 lb. 325 GLASS
   .117 gm Barium Carbonate
   .235 gm Soda Ash
   1.6 oz. Sodium Silicate
   Results: Fast Setting; high vitrification; self glazing. Clogs mold after multiple castings. Very fragile green ware

2) 5 lb. Ball Clay Mix
   10 lb. 140 Glass
   10 lb. 325 Glass
   .117 gm Barium Carb
   .235 gm Soda Ash
   .3 oz. Dispersant (Darvan)
   2 1/8 Gal. H20
   Results: Uncastable cracks in mold

3) 8.75 lb. Ball Clay Mix
   8.13 lb. 140 Glass
   8.13 lb. 325 Glass
   .117 gm Barium Carb
   .235 gm Soda Ash
   2 gal. H20
   Results: Good consistency but cracks in mold

4) 12.5 lb. Ball Clay Mix
   6.25 lb. 325 Glass

6.25 lb. 140 Glass
.117 gm Barium Carb
.235 gm Soda Ash
2 oz. Dispersant (Darvan)
4 oz. VEE Gum
2 gal. H20
Results: Good consistency but cracks in mold. Sticks to mold. Self-glazing.

5) 12.5 lb. Ball Clay Mix
12.5 lb. 325 Glass
.118 gm Barium Carbonate
.235 gm Soda Ash
2 oz. Dispersant
4 oz. VEE Gum
1 lb. Dry Celulose Fiber
2 gal. H20
Results: Good casting. Strong Green Strength. Sticks to mold after multiple castings. Self glazing.

All slips are highly vitrified. It appears that Ball Clay leaches to the surface of the casting. This causes problems with sticking.

4.0 CONCLUSION

This project confirms that finely graded glass is an effective body flux when substituted for other fluxing materials in clay mixes. Glass body flux lowers clay maturation temperatures and has the potential to improve the efficiency of clay production facilities. Additional work is needed to confirm specific clay body applications which will benefit most from the addition of glass.

The workability of mixtures containing glass is different from standard mixtures. More research in this area could be focused on finding additives (dispersants, plasticizers, etc.) that will improve the functionality of glass as a clay body flux.

APPENDIX A

RAW DATA FROM TESTS

DATA POINTS FOR CONE 06 RED

CONE 06

PERCENT GLASS	SHRINKAGE	ABSORPTION
25	9.8	8.97
50	7.6	7.9
75	8.2	5.97
100	8.3	2.38

CONE 04

PERCENT GLASS	SHRINKAGE	ABSORPTION
25	10	7.74
50	8.6	6.97
75	9.6	4.32
100	9.5	2.1

CONE 01

PERCENT GLASS	SHRINKAGE	ABSORPTION
25	11	5.12
50	9.6	4.78
75	10.5	3.21
100	10.5	1.17

DATA POINTS FOR CONE 06 WHITE

CONE 06

PERCENT GLASS	SHRINKAGE	ABSORPTION
5	9.0	11.5
10	9.5	8.52
15	9.5	8.92
20	8.0	8.98
30	8.5	9.12
40	8.0	7.93
50	7.0	7.97
100	7.0	2.26

CONE 04

PERCENT GLASS	SHRINKAGE	ABSORPTION
5	11.00	10.72
10	10.50	7.48
15	10.00	7.74
20	10.00	7.74
30	10.70	7.80
40	10.50	6.79
50	9.50	6.97
100	9.50	2.00

CONE 1

PERCENT GLASS	SHRINKAGE	ABSORPTION
5	11.50	7.80
10	10.50	5.38
15	10.50	5.08
20	11.00	5.10
30	11.50	5.12
40	11.00	4.68
50	10.50	4.56
100	10.00	1.20

DATA POINTS FOR CONE 6 RED TALC SUBSTITUTION

CONE 1

PERCENT TALC	SHRINKAGE	ABSORPTION
50	12	6.4
75	11.5	5.6
100	10.5	3.5

CONE 3

PERCENT TALC	SHRINKAGE	ABSORPTION
50	12	4.8
75	12	3.9
100	11.5	2.9

CONE 5

PERCENT TALC	SHRINKAGE	ABSORPTION
50	13.5	3.2
75	13	2.6
100	12	1.7

DATA POINTS FOR CONE 6 RED NEPH SY SUBSTITUTION

CONE 1

PERCENT NEPH SY	SHRINKAGE	ABSORPTION
25	10	7.3
50	12	7
75	10.5	5
100	10.5	4

CONE 3

PERCENT NEPH SY	SHRINKAGE	ABSORPTION
25	11.5	5.2
50	11.5	5.5
75	12.5	4.2
100	12.5	3.7

CONE 5

PERCENT NEPH SY	SHRINKAGE	ABSORPTION
25	12	3.9
50	12.5	3.5
75	14	2.1
100	13.5	1.9

DATA POINTS FOR CONE 6 WHITE (GLASS)

CONE 1

PERCENT GLASS	SHRINKAGE	ABSORPTION
20	13	7
40	12.5	6.9
50	13	5.9
80	12	6.1
100	10.5	4.7

CONE 3

PERCENT GLASS	SHRINKAGE	ABSORPTION
20	14	4.3
40	13.5	4.5
50	13.5	3.3
80	14.5	3.8
100	13.5	3.1

CONE 5

PERCENT GLASS	SHRINKAGE	ABSORPTION
20	14.5	1.9
40	14	2
50	14	1.9
80	15	1.4
100	14	1.2

DATA POINTS FOR CONE 6 WHITE (140 GLASS)

CONE 1

PERCENT GLASS	SHRINKAGE	ABSORPTION
50	13	7.5
100	12.5	6.3

CONE 3

PERCENT GLASS	SHRINKAGE	ABSORPTION
50	14	5.1
100	13.5	4.9

CONE 5

PERCENT GLASS	SHRINKAGE	ABSORPTION
50	14	1.9
100	15	3.9