Green Ware? Development of low temperature vitreous ceramics.

As a result of concerns about carbon emissions and broader environmental concerns, this research investigated the possibility of developing low firing temperature clay and glazes for use in studio ceramics, incorporating selected industrial and agricultural waste products from New South Wales, Australia.

This project was commenced in the middle of 2008. Two years previously, in America, Al Gore had popularized the debate using the movie *An Inconvenient Truth* (Guggenheim, 2006). In Australia, Prime Minister Kevin Rudd had been elected after describing climate change as the great moral challenge of our generation (Rudd, 2007). The motivation for embarking on this project arose from identification with these very publicly expressed concerns for the environment. The attribution of personal responsibility for the possible effect on the environment of firing relatively high temperature ceramics led to consideration of methods of clay formulation that would assist in reducing energy use and carbon emissions associated with studio ceramics.

Studio ceramics can be heated to temperatures across a continuum. At the low temperature extreme we have *Egyptian Paste,* a self-glazing clay of poor workability usually fired within a range of 900o - 1000o C, [Cone1 010 - 06) (Ceramics Today, nd). Peterson (2012a & 2012b) classifies Low-Fire as being Cone 06 to Cone 3 (999oC - 1100oC), and notes that studio ceramics fired in this range are usually relatively soft and absorbent.

Ceramic that is relatively soft and absorbent has not *vitrified* during firing. *Vitrification* is the process whereby clay forms a glassy ceramic that is not absorbent (American Ceramic

Society, 2005). Vitrification follows and

[1] Because the amount of time a clay is exposed to heat affects the product, (Norton & Hodgdon,1931) the combined effect of time and temperature is referred to as *heat work.* The extent of heat work applied is observed through the placement in the kiln of *pyrometric cones.* These *cones* are proprietary formulations of raw materials fashioned into elongated trigonal pyramids designed to soften and bend from an upright position when a certain amount of heat work has been completed. (Walker, 2009).

overlaps with a process of *sintering,* in which a porous mass densifies and strengthens (Green, Guillon & Rodel, 2008). The extent to which these processes occur within a given firing range depends to a large extent on the mix of materials that form a clay *body.*

There is extensive literature on the inclusion of industrial, municipal and agricultural waste in clay bodies. Denis Whitfield's (1985) work on clay from sand quarry tailings, and his later work on selected industrial wastes from New South Wales in Australia (Whitfield, 1993) provided an excellent basis for further research. This was because of the aim of using as many recycled constituent materials as possible, and the desirability of those materials being obtained from within New South Wales.

In selecting materials, some consideration had to be given to toxicity, availability, and impact on the commonly preferred characteristics of clay bodies. In the *raw* or unfired state, when forming processes are applied to malleable clay that stiffens as it dries, these include workability, the extent of shrinkage during drying and the dry strength obtained. Once the ceramic has been fired, desired characteristics can include fired strength, resistance to abrasion, and lack of permeability. As these fired characteristics depend considerably on the amount of sintering and vitrification achieved, two approaches for lowering the temperature of sintering and vitrification were adopted. One approach was to use materials of small particle size. The other was to include a range of flux materials.

This research made use of an iterative process of *triaxial blending* in which three batches of materials are blended in various proportions to produce a systematic variation in constituents (Currie, 2000). Normally this is a process that is applied to glazes. In this case, it was adapted to apply to clay bodies.

The Matrix program (Ewing, 2000) was used to predict melting temperatures, calculate coefficients of thermal expansion, and produce unity molecular

formulae to enable readers to formulate similar results using different materials.

As a result a low fire body was developed. The body is thixotropic and therefore difficult to knead and throw, but demonstrates that vitrified ceramics can be produced at 950 degrees centigrade. Absorption after boiling for 5 hours in water and standing for 24 hours was less than 1%. The ware is strong and has a clear ring when struck. Careful attention to firing temperature is necessary as slumping quickly results from over-firing, just as would occur with an over-fired porcelain body.

Smout Low-Fire body (Cone 09 – 08)

Bungendore Tailings 35.94 Marulan Tailings 27.50 Unimin Cullet 150 11.25 Nepheline Syenite 200 7.88 Talc Plustalc N275 3.38 Gerstley Borate 11.25 Cryolite Synthetic 1.69 Lithium Carbonate 1.13

100

Epsom Salts 0.3 Barium Carbonate 0.65

The unity molecular formula of this body, omitting trace elements and with fluxes unified (as if for a glaze) is:

KNO	K2O	NaO2	CaO	MgO	BaO	Al2O3	P2O5	B2O3	SiO2	TiO2
0.340	0.088	0.252	0.299	0.209	0.012	0.470		0.172	3.506	0.017

Alumina to silica ratio Coefficient of expansion Estimate firing temp (as glaze)

7.46 10.01 1230oC

The unity molecular formula with alumina unified (convention for a clay) is:

KNO	K2O	NaO2	CaO	MgO	BaO	Al2O3	P2O5	B2O3	SiO2	TiO2
0.724	0.188	0.536	0.635	0.445	0.026	1.000		0.367	7.459	0.035

A number of glazes were also developed using recycled materials. Readers wanting to produce a similar body and glazes at these temperatures could use powdered earthenware clay instead of the tailings in the recipes above and below, and replace the sugar cane ash with wood ash.

Cone 09 - 08 Clear Gloss

Gerstley Borate Unimin Cullet Bungendore tailings Sugar cane ash Marulan Tailings Lithium Carbonate

27.50 22.50 30.00

4.00

1.00 15.00 100.00

For those who make use of formulae to develop recipes, it will be useful to note that the molecular unity formula, omitting trace elements and with fluxes unified is:

Alumina to silica ratio 13.74 Coefficient of expansion 9.63 Ionic potential 14.2

KNO	K2O	NaO2	CaO	MgO	Al2O3	LiO2	B2O3	SiO2	TiO2
0.111	0.010	0.101	0.191	0.040	0.071	0.657	0.149	0.972	0.005

Additions

Cobalt Carbonate Chrome Oxide

0.25 Cone 09 - 08 Blue gloss 0.50 Cone 09 - 08 Green gloss

A bowl thrown from this body and glazed with the clear glaze with 0.5% chrome oxide added is shown below.

This research demonstrates that it is possible to produce vitrified ceramics below 1000 degrees Centigrade. The workability of the body developed is relatively poor and would need to be improved if the body was to be used in a standard studio setting. It may be fruitful to explore alternative production techniques, such as dry pressing or 3D printing using a body of this type. Those firing at higher temperatures could also make use of the recipe and formulae supplied to develop additives to decrease porosity.

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