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USES OF TALC/ALBITE ROCK
PRODUCTION OF 'CORDIERITE' CERAMICS

S.A. Department of Mines and Energy

PR No. 1

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USES OF TALC/ALBITE ROCK

Progress Report No. 1

PRODUCTION OF 'CORDIERITE' CERAMICS

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for Norton Jackson
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1. INTRODUCTION

A large proportion of the talc mined from the Gumeracha area of South Australia is unusual in that it is associated with a varying amount of albite feldspar which in the past has affected many of the traditional markets for which talc is mined. Further, much of the talc is iron-stained to varying degrees resulting in a discoloured product when ground which further limits its marketability. As neither the presence of albite nor iron-staining is uniform in distribution the area has generally been worked with a view to obtaining a number of talc grades, designated 1st grade through to 4th grade depending upon the degree of iron staining. This is achieved primarily by hand sorting, particularly for the higher 1st and 2nd grade products.

Although the feldspar is randomly distributed throughout the deposits within the area some massive feldspar bodies have been encountered. Feldspar proportions in general vary from zero to 30 percent but results from recent drilling have determined that selected areas may be mined and bulked to produce a product with a relatively consistent level of feldspar.

Since the mining of a consistent product, containing a pre-determined level of albite, appears feasible it is desirable to obtain markets for that product. Without beneficiation, the most likely markets, in addition to the current 'filler' extender and coating markets look to be in the ceramic field.

Work already completed has shown that a body incorporating a high proportion of talc, which contains approximately 25% of albite, could, in conjunction with a plastic clay, be used to manufacture low absorption floor tiles by fast firing techniques.

The current investigation considers the utilization of material designated as 3rd or 4th grade talc, depending upon colour, containing approximately 5% of albite, for the manufacture of cordierite bodies.

Cordierite ($2MgO\ \ 2Al_2O_3\ \ 5SiO_2$) bodies have unusually low coefficients of thermal expansion and therefore are valuable for use in areas where thermal shock is of primary importance. Bodies containing essentially cordierite have been used successfully for production of high tension insulators, refractory pieces, particularly kiln furniture and ceramic cooking ware.

The present work was designed to investigate the area of unglazed cordierite ceramics which may be suitable for kiln furniture.

2. CORDIERITE

Cordierite, $2MgO\ 2Al_2O_3\ 5SiO_2$, contains 13.7% MgO, 34.9% Al_2O_3 and 51.4% SiO_2. In nature it is found in granites, gneisses, schists and in contact metamorphic zones. Industrially it is manufactured from talc, kaolinite, magnesia and alumina. Segnit & Holland (1971) investigated the use of clinoclore, a chlorite of composition $Mg_5Al_2Si_2O_{10}(OH)_8$, and a good quality kaolinite for manufacturing cordierite which began to form at temperatures as low as 1140°C associated with christobalite and mullite phases. With increasing temperature these phases were eliminated resulting in only cordierite at 1225°C. Geller & Insley (1932) produced porous cordierite bodies, with high thermal shock resistance and low thermal expansion, from bodies consisting of talc, kaolin and corundum (or calcined alumina) at temperatures of 1350°C and showed that an increase in cordierite was directly responsible for a decrease in thermal expansion. Numerous other workers have also investigated various talcs and clays for producing cordierite, generally at temperatures above 1300°C. Theiss (1943) studied the formation of vitrified cordierite bodies in systems containing feldspar, beryl, spodumene, nepheline-syenite and feldspar-zinc oxide combinations to evaluate their effect on extending the firing range of vitrified products. Generally cordierite bodies have short vitrifying ranges which creates problems in industrial manufacturing and as early as 1930 in Germany, alkalies, iron oxides and red-firing clays were added to cordierite insulator mixes to extend their firing ranges.

Data produced by Theiss shows that feldspar, nepheline syenite and feldspar-zinc oxide used as a flux in vitrified cordierite bodies did extend their vitrification firing ranges.

It is well established that cordierite may form at different temperatures depending upon the physical and chemical properties of the constituents. For example, the work previously mentioned of Segnit and Holland produced a body of only cordierite composition at 1225°C and a well crystallised cordierite with minor mullite and cristobalite phases at 1200°C using clinochlore and kaolinite. Presumably because the chlorite and kaolinite undergo major structural breakdown at temperatures below 1000°C, the resulting disordered structures are favourable for the early development of stable phases. However, in the case of talc, kaolinite and alumina combinations investigated by Hughan (1952) and the kaolinite, magnesia and silica, or alumina magnesite and silica bodies investigated by Jelasic and Kacian (1967) temperatures above 1300°C were necessary to form cordierite.

Takker et al (1974) studied the production of a dense-sintered monomineralic cordierite body using finely dispersed glass powders and raw clay. They report that X-ray photographs taken at 900°C show that the diffraction peaks of cordierite are clearly developed between 1100°C and 1450°C. This becomes the unique crystal phase. The process whereby an initial crystal phase is completely transformed into cordierite is complete at 1100°C. This is in contrast to cordierite development in traditional bodies, as already mentioned, where cordierite does not begin to form below temperatures of approximately 1150°C.

Thus cordierite may be synthesised relatively easily from a variety of materials by selecting components and blending them in the amount required by the stoichiometric formula of cordierite. This uncomplicated procedure is, however, only partially satisfactory since the completeness of the reaction and mineralogy of the final product is dependent upon the firing temperature and soak times, the fineness of the components, the decomposition and the degree of reactivity of the components. Additional variables have been found to be of relevance, such as the presence of fluxes and mineralizers to extend the sintering range and promote self glazing of vitrified products and the addition of excess alumina to broaden the firing range and reduce the thermal expansion of a cordierite body (Basta and Said (1973).

3. EXPERIMENTAL WORK

3.1 Materials

3.1.1 Talc

The talc was a 3rd grade yellowish-pink material (minus 200 mesh) designated as Jarvind Super-Fine T/2, preground to minus 75 micrometres supplied by Jarvis Industries Pty Ltd. Analysis by X-ray diffraction shown in Table 1 indicated dominant talc with approximately 5% of albite and a trace of dolomite. A possible faint trace of quartz, outside the limit of estimation, was indicated. The chemical analysis given in Table 1 indicates a soda content of 0.56%, confirming the albite estimation, and a 0.13% level of calcium which may be attributed to dolomite (approximately 0.5%). Ferric and ferrous oxides account for 2.9% of the composition. If the talc were of ideal composition then the magnesium would account for 57% of the silica leaving an excess of approximately 4% of which 3.3% may be attributed to the albite and the remainder to excess silica.

A dry screen size analysis is given in Table 2.

3.1.2 Clay

The clay selected for the study is a high alumina refractory clay from Williamstown in South Australia containing approximate equal proportions of kaolinite and sillimanite and sub-dominant (15-30%) mica (muscovite and paragonite). Accessory quartz estimated at between 5 & 15% is present together with a trace of pyrophyllite (<5%). The clay is non-plastic, white in colour, and contains 0.5% ferric iron, 43.4% Al_2O_3, 44.3% SiO_2, 1.36% TiO_2, 0.52% Na_2O (attributed to paragonite) and 1% K_2O (muscovite). A complete analysis is shown in Table 1.

3.2 Body Composition

A 1:3 molar mix of talc and clay was chosen as the experimental body composition. On a fired basis the mix contained primarily 10% MgO, 32% Al_2O_3 and 53% SiO_2 composition thus corresponds to a formulation MgO:1.24 Al_2O_3:3.5 SiO_2. Theoretical cordierite contains 13.6% MgO, 35% Al_2O_3 and 51.4% SiO_2. (MgO:Al_2O_3:2.5 SiO_2).

The presence of sillimanite, roughly estimated from the chemical analysis and X-ray Diffraction to be 23%, complicates the calculation of the most desirable body composition since it is expected that sillimanite will remain unreacted in the fired body and thus a proportion of the alumina will not be available for cordierite formation. A percentage of the silica will similarly be unavilable for reaction.

Although theoretical calculations were done at this stage to estimate the proportions of magnesia, alumina and silica which will be free for formation of cordierite and protoenstatite it was considered preferable to obtain accurate data from the analysis of the fired products prior to postulating any alteration of the basic mix.

3.3 Preparation

The clay was initially ground in a Disc Pulverizer to a nominal fineness of 600 micrometres (25 mesh B.S.S.). The clay and preground 75 micrometre(200 mesh B.S.S.) talc was then wet milled in an aqueous slurry at 50% solids in 3 gallon capacity. Porcelain Ball Mills to (a) finer than 300 micrometres (52 mesh B.S.S.) (b) finer than 75 micrometres (200 mesh B.S.S.) and (c) the sizing shown in Table 3 where 20% of material was coarser than 300 µm (52 mesh B.S.S.) and 27% was between 300 and 53 µm (52 and 300 mesh B.S.S.). The ground bodies were dried, re-ground to minus 600 µm (25 mesh B.S.S.), moistened with 7% water and rubbed through a 1.2 mm (14 mesh B.S.S.) screen to produce a granulate for pressing. The bodies were stored in air-tight containers for a minimum of 24 hours to attain a uniform moisture content throughout the material prior to pressing.

3.4 Pressing of Samples

Test pieces consisting of 50 mm square 10 mm thick tiles were pressed on flat from each body in a mild steel die at a pressure of 224 kg/cm^2. Additionally, bars 230 mm long by approximately 25 mm square cross section under a pressure of 100 kg/cm^2 loading perpendicular to the 230 mm by 25 mm face were made from the coarser body. Test pieces were dried at 105°C immediately after pressing.

4. TEST PROCEDURES AND RESULTS

4.1 Firing

A number of firing conditions were used during this initial stage of investigation to determine the general behaviour and potential of the talc-clay mixture for the production of cordierite bodies.

1. The coarse tile body was fired in an electric kiln from 1250°C to 1370°C at 30°C intervals over a 4½ hour period including 1 hour soak at peak temperature. Two samples previously fired to the above cycle at 1280 and 1310°C were re-fired at 1280°C over a 7 hour firing period including a 3½ hour soak at peak temperature to determine their stability on re-firing.

2. The samples pressed from the material finer than 300 µm (52 mesh B.S.S.) were fired in a Bickley gas kiln between 1250°C and 1400°C at 30°C intervals. Total firing time was 4 hours including a 1 hour soak period.

3. The pressed bars were fired in the Bickley gas kiln between 1250°C and 1370°C at 30°C intervals to the above cycle.

4. The fine grained body (minus 75 µm; 200 mesh) was fired in an electric kiln at 1270°C, 1290°C and 1310°C in 1 hour followed by a 2 hour soaking period.

4.2 Mineralogy

The mineralogy of the fired bodies was determined by X-ray Diffraction techniques. Approximate proportions of cordierite and sillimanite were estimated by averaging the four major peaks of each mineral.

All traces showed that indialite (Miyashiro (1957)), the hexagonal polymorph of cordierite was formed on firing at temperatures as low as 1250°C in association with sillimanite, protoenstatite and a trace of quartz.

4.2.1 Fine Grained Samples - Less than 75 μm

At 1270°C indialite highly crystalline, was produced in association with an accessory amount of remanent sillimanite and a trace of quartz. A trace of protenstatite was detectable. With increasing temperature the protoenstatite reacted with alumina to form indialite, and was not detectable at 1290°C. A trace of quartz was still present.

4.2.2 Material Finer than 300 μm (52 mesh)

Between 1250°C and 1370°C indialite increased in relative proportion and sillimanite decreased. Protoenstatite was present up to 1310°C and a trace of quartz (2-3%) remained throughout the firing series.

Generally the degree of crystallinity of the indialite was not found to vary significantly although additional work is necessary to confirm this aspect. Broadly, the degree of crystallinity throughout the series was high.

4.2.3 Coarse Grained Samples

These samples fired between 1250°C and 1370°C produced similar mineralogical associations to those determined for the fired samples of material finer than 300 micrometres with a few notable variations.

The proportion of indialite formed during firing at temperatures up to 1310°C did not increase as previously noted for the finer grained samples nor did the proportion of sillimanite appear to decrease. At 1340°C and 1370°C, however, a significant increase in indialite was observed although only a minor decrease in sillimanite was detectable. Protoenstatite was present up to 1280°C but could not be definitely identified at 1310°C. A trace of quartz, constant and low (2-3%), was detected throughout the series.

Two samples initially fired at 1280 and 1310°C but refired at 1280°C with a 3½ h soak were analysed for comparison with results obtained from the initial firing. Upon refiring protoenstatite was eliminated from the 1280°C sample and the proportion of sillimanite also appeared to decrease. The formerly higher fired (1310°C) sample remained similar.

For comparative purposes a sample of a German manufactured 'cordierite' setter plate was analysed. Interestingly it was found to be very similar to the laboratory produced samples in that it was composed of indialite and sillimanite (possibly a mixture of sillimanite and mullite), in the relative proportions of 2.3:1. The laboratory produced material showed a higher indialite to sillimanite ratio varying from approximately 2.8-9.3:1. No protoenstatite or quartz was detectable in the comparative material.

Mineralogy of the fired samples is shown in Table 4.

4.3 Physical Properties

4.3.1 Fine Grained Bodies

The fine grained 75 μm (200 mesh) bodies formed hard, dense highly crystalline and near vitrified products at 1270-1310°C. Notable distortion was evident at 1310°C and a heavy glaze was well developed on the surface of the tile. A very thin glaze was already beginning to form at 1290°C. The bodies were light grey in colour. Firing shrinkage at 1270°C was 3.9% decreasing slightly to 3.4% at 1290°C. An accurate measurement at 1310°C was not possible due to distortion but was roughly 2.7 - 3%. Water absorptions varied from 2.3% at 1270 and 1290°C to 0.31% at 1310°C.

4.3.2 Bodies Finer Than 300 μm (52 mesh B.S.S.)

These fired in the gas kiln produced strong crystalline porous bodies ranging in colour from off-white at 1250°C to greyish at 1340°C and tan at 1400°C. Firing shrinkage, water absorption (2 hr boil) apparent porosity and bulk density results shown in Table 5 indicate an initial decrease in water absorption from 13.4% and 1250°C to 4.4% at 1340°C followed by an increase to 10.3% at 1400°C. Firing shrinkages range from 2.1% to 2.5% with the exception of the 1340°C samples which recorded a 3.2% firing shrinkage. The absorption and shrinkage results are consistent with an increase in bulk density at this temperature from an average at other temperatures of 1.99 (range 1.97 - 2.02) to 2.13 and a significant reduction in the apparent porosity of the body from 22.9% at 1310 to 9.7% at 1340°C. Above 1340°C the fired tiles show an increase in surface porosity. Examination suggests that a localized sintering process is taking place. The pores or vesicles occur throughout the bodies and are surrounded by a yellowish crystalline halo. Identification of this mineral has not been undertaken at this time.

The modulus of rupture of the pressed, gas fired bars was determined under a three point system in general accordance with the method recommended in Australian Standard AS 1774.3 1977 (Determination of cold modulus of rupture). A loading rate of 5 N/sec was maintained to failure to accommodate for the smaller cross sectional area samples. The M.O.R. was calculated using the formula

$$R = \frac{3wl}{2bd^2}$$

where R : Modulus of Rupture (MPa)
W : Force at failure (Newtons)
l : Span between bearing edges (mm)
b : Width of test specimen (mm)
d : Depth of test specimen (mm)

Results shown in Table 5 are in general agreement with the other physical parameters already considered and the highest strength recorded of 34 MPa at 1340°C appears to verify that an increased rate of sintering does occur in the range of 1340°C with a subsequent reduction in porosity and water absorption and increase in the shrinkage and bulk density of the body.

Above 1340°C the decrease in strength is considered to be attributed to increased porosity and discontinuity of the mineral grains.

Unfortunately only one sample was available for a Modulus of Rupture determination at each temperature and two of the samples, notable the 1280 and 1310°C samples, do show minor laminations in the broken face running perpendicular to the direction of the applied breaking force. Obviously these were induced during pressing since in the cross sectional broken face of the bars the laminations are concave relative to the direction of the applied pressing force. Although they were not major zones of weakness, since they pass through discrete mineral grains in the broken faces they may have reduced the strength of these specimens.

4.3.3 Coarse-grained Body

As already discussed the clay component of the body contains a large proportion of sillimanite (approximately 35%) which is a hard and very tough mineral. It is, therefore, this mineral which forms the bulk of the plus 300 μm (52 mesh) material in the body. The total sillimanite content of the body composition is estimated at roughly 23%.

Firing in an electric kiln produced crystalline porous products ranging in colour from cream at 1250°C to light brown at 1340°C and a grey speckled product at 1370°C.

Compared with the finer grained gas fired body water absorptions, porosities and bulk densities were of the same general order for all temperatures between 1250°C and 1370°C (a 1400°C sample was not fired) with the exception of the 1340°C sample. At this temperature the body did not sinter to the degree observed in the finer grained sample and its behaviour was a significant reversal showing an increase in water absorption, apparent porosity and decrease in bulk density.

Shrinkages for the coarser body were higher at 1250°C than for the finer grained body but decreased with firing temperature to a minimum of 1.6% at 1340°C followed by a slight increase to 1.73% at 1370°C accompanied by a decrease in water absorption and apparent porosity and an increase in bulk density.

At 1340°C and 1370°C the surface porosity described previously became pronounced, particularly at the higher temperature, which is attributed to melting of discrete mineral grains. A distinct orange-red mineral, unidentified at this stage, was observed within some of the larger vacuoles surrounded by the yellowish crystalline halo.

The physical properties of the fired samples are shown in Table 6.

The 1280°C and 1310°C samples, refired at 1280°C for 7 hours including a 3½ hour soaking period, recorded a slight expansion of 0.2% on refiring and a very minor reduction in their water absorption (2 hour boil). Results are presented in Table 7.

5. DISCUSSION

The investigation conducted to date has shown that synthetic indialite is readily produced from a combination of 32.8% Gumeracha talc, containing 5% albite, and 67.2% of high alumina Williamstown clay during fast firing cycles at temperatures as low as 1250°C. The indialite shows a high degree of crystallinity at all temperatures which did not appear to vary significantly over the range of temperature and time conditions imposed.

Increased firing temperature and soaking time alters the mineralogy of the fired samples within a series (constant particle size). Broadly, with increasing temperature, indialite increases in proportion and sillimanite decreases. Protoenstatite disappears with increasing temperature and was not detectable above 1310°C. However, its presence or absence in the fired product is also dependent upon soaking time and fineness of the mix components, particularly sillimanite.

In very fine grained samples protoenstatite was not detected at 1290°C but in coarser particle sized samples produced from cycles with shorter soaking times it persists to a higher temperature. Protoenstatite dispersed upon refiring the 1280°C coarse grained sample at the same temperature with a soak of 3½ hours.

The particle size of the mineral components of the mix is the most significant controlling factor on the type and nature of the fired product. Fine grinding of mineral components produces dense vitrified (or low absorption) products at 1270°C but coarser ground samples remain porous up to at least 1400°C when fast firing cycles are used.

The anomalous physical result obtained from a gas fired product at 1340°C remains unexplained at this stage. Further investigation at this temperature, which is regarded as the maximum firing temperature for coarser grained samples since higher temperatures produce localized sintering in the body, is necessary.

Refiring of samples, initially fired at 1280°C and 1310°C, at 1280°C in an electric kiln resulted in only a minor decrease in water absorptions and in the sillimanite proportion of the lower temperature sample, which has reacted with the protoenstatite, indicating that the initially-formed components were not stable and longer firing periods are required.

6. CONCLUSIONS

The preliminary investigation indicates that the Gumeracha talc and Williamstown clay mix has considerable potential for the production of both vitrified and porous cordierite (indialite) bodies, the properties of which will depend primarily upon the fineness of the initial components but also upon the firing cycle.

The low temperature of formation of indialite, found by most investigators of talc-clay bodies to be in excess of 1300°C suggests that production of cordierite products may be undertaken at temperatures of 1250-1300°C and that the required physical properties of the products may be controlled by either varying the grinding criterion for the initial mix or by the addition of pre-fired 'grog' to a fine grained unfired body.

Properties of the fired ware demonstrate that strong bodies of satisfactory appearance and having a range of porosities can be produced by relatively simple rapid preparatory and firing operations.

7. RECOMMENDATIONS

Prior to this investigation being undertaken it was envisaged that the relationship of particle size in the pre-fired body would be highly relevant and this aspect was mentioned in the project proposal. It is therefore recommended that this area be further investigated in the continuation of the project together with a study of 'grog' additions to the basic fine grained body.

Further work is necessary to resolve the firing behaviour during sintering in the area of 1340°C and this would be related to the dependancy upon grinding.

Since low temperature vitrification is possible in finely-ground bodies, examination of the firing range of vitrified cordierite (indialite) ceramic articles, such as cooking ware is recommended. The area of glazed products should also be considered.

The thermal shock resistance of the synthetic bodies, not investigated to date, should be investigated in relationship to specific products, such as refractory kiln furniture and cooking ware, within the scope of the ongoing investigation.

These recommendations are necessary in order to confirm the suitability of the body for commercial exploitation in the fields of refractories and low expansion ceramics. Additional tests, not recommended at this stage, would be necessary to establish suitability as electrical porcelain.

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TABLE 1: MINERALOGY AND CHEMICAL ANALYSIS OF RAW MATERIALS

	Talc (CE 5199)	Clay (A 4797)	
Talc	Major	Kaolinite	CD*
Feldspar (albite)	app. 5%	Sillimanite	CD
Dolomite	Trace	Muscovite & Paragonite	SD
Quartz ?	Slight trace	Quartz	A
		Pyrophyllite	Tr
SiO_2	61.2	44.31	
TiO_2	0.16	1.36	
Al_2O_3	1.51	43.42	
Fe_2O_3	0.83	0.50	
FeO	2.07	-	
MnO	0.01	<0.01	
MgO	28.44	0.09	
CaO	0.13	0.11	
Na_2O	0.56	0.52	
K_2O	0.06	1.0	
P_2O_5	0.10	0.01	
L.O.I.	4.70	7.66	
	99.77	98.98	
H_2O^+	4.46		
H_2O^-	0.24		

*CD	Co-dominant (approximately equal proportions)
SD	Sub-dominant (15-30%)
A	Accessory (5-15%)
Tr	Trace (less than 5%)

TABLE 2: DRY SCREEN ANALYSIS OF TALC SAMPLE

Size µm	Screen Sizing B.S.S.	Cumulative % Retained
+150	100 mesh	0.02
-105	150 mesh	0.02
- 75	200 mesh	0.26
- 53	300 mesh	2.28

TABLE 3: WET SCREEN ANALYSIS OF COARSE TALC/CLAY BODY

Size µm	Screen Sizing B.S.S.	Cumulative % Retained
300	+ 52 mesh	20.6
212	72 mesh	27.6
150	100 mesh	33.5
105	150 mesh	38.4
75	200 mesh	43.7
53	300 mesh	47.4

TABLE 4: MINERALOGY OF FIRED SAMPLES

Temperature °C	Composition Indialite	 Sillimanite	 Protoenstatite	 Quartz
Fine grained samples (less than 75 micrometre (200 mesh B.S.S.)				
1270	D (51)	A (9)	Tr	Tr
1290	D (52)	A (9)	-	Tr
Samples finer than 300 μm (52 mesh B.S.S.)				
1250	D (37)	A (13)	Tr+	Tr
1280	D (57)	A (11)	Tr+	Tr
1310	D (53)	A (10)	Tr	Tr
1340	D (61)	A (9)	-	Tr
1370	D (64)	A (7)	-	Tr
Samples coarser than 300 μm (52 mesh B.S.S.)				
1250	D (46)	A (13)	Tr	Tr
1280	D (49)	A (12)	Tr	Tr
1310	D (49)	A (13)	-	Tr
1340	D (58)	A (12)	-	Tr
1370	D (65)	A (10)	-	Tr
Refired samples (fired 1280°C - 7 hours, 3½ hr soak)				
Initial Temperature °C	Composition Indialite	 Sillimanite	 Protoenstate	 Quartz
1280	D (50)	A (10)		Tr
1310	D (46)	A (12)		Tr
Standard Cordierite Setter Plate				
	D (43)	A* (19)		

NOTE: The figures in brackets demonstrate the variation in amounts of the two major components but bear no relation to percentages. The figures were derived from a geometric average of four peak heights of the X-ray patterns.

* May be a mixture of sillimanite and mullite.

LEGEND:

D	Dominant
A	Accessory (5-15%)
Tr	Trace (0-5%)

TABLE 5: GAS FIRED TILE SAMPLES - FIRED PROPERTIES

Firing * Temperature °C	Firing Shrinkage %	Water Absorption %	Apparent Porosity %	Bulk Density	Modulus of Rupture MPa
1250	2.4	13.4	26.5	1.97	26.9 (274 kg/cm^2)
1280	2.5	11.8	24.3	1.99	28 (285 kg/cm^2)
1310	2.2	10.1	22.9	2.0	25 (225 kg/cm^2)
1340	3.2	4.4	9.7	2.13	34 (347 kg/cm^2)
1370	2.3	9.2	20.4	2.02	30.5 (311 kg/cm^2)
1400	2.1	10.3	20.7	1.98	

*4 hour firing time including 1 hour soak on peak temperature.

TABLE 6: ELECTRIC FIRED TILE SAMPLES - FIRED PROPERTIES

Firing* Temperature °C	Firing Shrinkage %	Firing Wt Loss %	Water Absorption %	Apparent Porosity %	Bulk Density
1250	2.85	6.4	12.1	24.3	2.0
1280	2.5	6.4	11.7	23.5	2.0
1310	1.67	6.4	12.5	24.7	1.98
1340	1.6	6.4	13.8	26.5	1.92
1370	1.73	6.4	10.3	20.6	2.01

4½ hour firing including 1 hour soak at peak temperatures.

TABLE 7: RE-FIRED SAMPLES

Initial Firing			Re-firing				
Temperature °C	Total Time (hrs)	Soak (hrs)	Temperature °C	Total Time (hrs)	Soak (hrs)	Water Absorption %	Refiring Shrinkage %
1280	4½	1	1280	7	3½	11.3	-0.2
1310	4½	1	1280	7	3½	12.0	-0.2

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20 February 1979

The Director-General
S.A. Department of Mines and Energy
P.O. Box 151
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USES OF TALC/ALBITE ROCK

Progress Report No. 2

Investigation and Report by: Michael D. Ware.

Acting Manager, Materials Division: Dr William G. Spencer.

WG Spencer
for Norton Jackson
Managing Director

1. INTRODUCTION

Previous investigation of the ceramic behaviour of low grade talc (P.R. No. 1 MD 1/1/228) in conjunction with a refractory clay indicated that Indialite (a hexagonal polymorph of cordierite) could be manufactured at temperatures as low as 1250°C. Formation of this mineral in major proportions in certain ceramic bodies, particularly those which operate in situations of high thermal shock and intermittant firing conditions is advantageous since, in general, cordierite bodies exhibit extremely low coefficients of thermal expansion and high resistance to thermal shock.

The initial investigation was based upon a 1:3 molaar mix of Gumeracha 3rd grade talc and Williamstown high alumina refractory clay. The talc was of low grade quality due to the presence of feldspar (approximately 5%) and discolouration. The clay was basically a kaolinite-sillimanite mixture with 15-30% of muscovite and paragonite and minor quartz and pyrophyllite, analysing 43% Al_2O_3 and 44% SiO_2. Cordierite was detected at all firing temperatures up to 1370°C in conjunction with unreacted sillimanite. Test tiles produced by pressing, fired to produce high strength porous products indicating that the talc-clay bodies may have some potential in refractory manufacture.

Subsequent work, reported herein, has briefly examined the behaviour of a similar body using Birdwood refractory clay in lieu of the Williamstown material. This substitution of clay was requested by a local refractory manufacturer who has indicated some interest in the initial results and for economic reasons would prefer to use the Birdwood clay.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Talc

Jarvind Super-Fine T/2, preground to minus 75 micrometres (200 mesh B.S.S.) supplied by Jarvis Industries Pty Ltd. The material contains dominant talc, approximately 5% of albite, a trace of dolomite and possibly quartz. A chemical-analysis is given in Table 1.

2.1.2 Clay

Minerals Pty Ltd K2, refractory clay preground to 63 micrometres (250 mesh B.S.S.). A chemical analysis is given in Table 1.

2.2 Body Composition

A 1:3 molaar mix of talc and clay (weight per cent 32.8 Clay:67.2 Clay) was selected as the experimental body composition. On a fired basis the mix contained primarily 56% SiO_2 30% Al_2O_3 and 9.8% MgO, corresponding to a formulation $MgO\ 1.2\ Al_2O_3:3.7\ SiO_2$ (Theoretical cordierite - $MgO:Al_2O_3:2.5\ SiO_2$).

The chemical composition of the mix is given in Table 2.

2.3 Preparation

The raw materials were thoroughly mixed dry prior to addition of moisture to produce a body suitable for extrusion. The body was allowed to mature for 24 hours in a sealed container prior to extrusion using a laboratory Bolton de-airing extruder to produce a 25 mm column for firing trials. A slightly larger extruder capable of producing a column of 50 mm by 25 mm cross section was also used but failed to produce a column.

The extruded column was cut into individual slugs for testing.

2.4 Test Procedures and Results

2.4.1 Extrusion and Drying Behaviour

The body extruded satisfactorily at 30% moisture, wet weight basis, to produce a smooth faced, moderately weak, soft column which wire cut poorly. Some improvement would be gained by extruding stiffer, particularly in the wire cutting behaviour.

During drying, under static conditions at 35°C and 105°C, each sample developed a single longitudinal crack. Dry samples although of low strength could be handled satisfactorily. Drying shrinkage was 4.85%.

2.4.2 Fired Results

Two firings at 1250°C and 1350°C were undertaken in a Bickley gas fired kiln over a 4 and 4½ hour period respectively including a half hour soak at peak temperature.

Firing at 1250°C produces a high strength porous, greyish-yellow product. Firing shrinkage was 3.65% and compressive strength 60 MPa (615 kg/cm^2) measured parallel to the cylindrical axis. Absorption of the fired material determined after 24 hour of cold water immersion, was 20.4% relative to the dry sample weight.

An X-ray diffraction trace of the fired product indicated the presence of well crystalline indialite with a trace of protoenstatite and mullite and a very minor (1%) trace of quartz.

At 1350°C the material transforms into a greenish-black, molten, low viscosity mass.

4. CONCLUSIONS

The combination of talc and Birdwood clay examined lacksthe refractory properties of the previously examined talc and Williamstown clay body and is unsuitable for general refractory applications. However, the association of high strength and a substantially cordieritic mineralogy at 1250°C implies that ceramic articles may be manufactured suitable for applications which demand both strength and low thermal expansion. (The latter property is only assumed at this stage based upon the determined mineralogy).

Both drying and firing shrinkages may be reduced with stiffer extrusion which should also eliminate cracking during drying. The low green and dry strength may be substantially improved by addition of more plastic clays, or a small quantity of bentonite to the mix.

The failure to obtain an extrusion column in the larger machine is regarded as predominantly a limitation of the machine rather than a major problem of the body. The particular machine used is fitted with a high pitch auger with a high ratio of bore to auger diameter (i.e. 0.61) which in effect is inadequate for feeding unctuous materials.

In consideration of the data obtained and implied therefore it is concluded that the body, with minor modification to improve its green strength, suitably prepared and fired may be satisfactory for earthenware cooking products, general high strength non-refractory porous ceramic articles and laboratory ware.

5. RECOMMENDATIONS

Further work on the utilization of low grade Gumeracha talc should follow the general recommendations given in Progress Report No. 1 (MD 1/1/228). With relation to the talc/Birdwood clay mixture the investigation should include aspects of :

1. Improving the green strength of the body.
2. Slip casting - cookware, laboratory ware and general earthenware products (including glazing).
3. Alternative forming methods such as "jiggering".
4. Determination of the acid resistance of the product.

The refractory applications of the talc/Williamstown clay body should be directed toward the aspects of body preparation and in particular a study of "grog" additions to a basic fine grained body of the same composition for production of refractory kiln furniture.

The refractory properties of the talc/Birdwood blend are poor and no further work on the development of refractories from this blend is recommended.

dk:3.

TABLE 1: MINERALOGY OF RAW MATERIALS

	Talc (Gumeracha 3rd Grade)	Clay (Birdwood K2)
SiO_2	61.2	45.3
TiO_2	0.16	1.7
Al_2O_3	1.51	38.3
Fe_2O_3	0.83	0.4
FeO	2.07	-
MnO	0.01	-
MgO	28.44	0.05
CaO	0.13	0.06
Na_2O	0.56	-
K_2O	0.06	0.01
P_2O_5	0.10	-
L.O.I.	4.70	13.8
	99.77	99.71

TABLE 2: CHEMICAL COMPOSITION OF EXPERIMENTAL MIX

	Fired Basis
SiO_2	56.4
TiO_2	1.37
Al_2O_3	30.38
Fe_2O_3	0.59
FeO	0.71
MnO	-
MgO	9.8
CaO	0.09
Na_2O	0.19
K_2O	0.1
P_2O_5	0.03
	99.68

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USES OF TALC/ALBITE ROCK

S.A. Department of Mines and Energy

PR No. 3

MD 1/1/228 April 1979

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6 April 1979

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USES OF TALC/ALBITE ROCK

Progress Report No. 3

Investigation and Report by: Micahel D. Ware.

Acting Manager, Materials Division: Dr William G. Spencer.

W.G. Spencer
for Norton Jackson
Managing Director

1. INTRODUCTION

The investigation of the ceramic behaviour of low-grade Gumeracha talc has previously considered the suitability of a number of talc bodies for manufacture by pressing and extrusion.. The most recent work has been directed toward examination of the casting behaviour of bodies, incorporating talc, which may be suitable for the production of stone and earthenware products in general and more specifically for ovenware.

Ceramic ovenware is considered since previous work has shown that simple talc-clay bodies, incorporating local materials, readily produce cordierite (indialite) at the normal stoneware firing temperatures (1250°C - 1300°C). Bodies incorporating a percentage of cordierite exhibit a lower coefficient of thermal expansion than normal stoneware bodies in which cordierite is absent and thus they show superior heat-shock resistance, an important characteristic of quality ovenware bodies.

Although there is considerable merit in using a low expansion body for cookware there are disadvantages relating to the problems of glazing since most glazes have coefficients of 6-9 × 10^{-6} °C whereas a body which contains cordierite may be expected to have a thermal coefficient of 4 × 10^{-6} °C or less. Thus, since the glaze is in tension crazing generally results. Special glazes are therefore normally required for cordierite bodies, or alternatively self glazing bodies are developed.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Talc

Jarvind Super-fine T 2, preground to minus 75 micrometres supplied by Jarvis Industries Pty Ltd (Minerals Pty Ltd). The material contains dominant talc, approximately 5% of albite, a trace of dolomite and possibly quartz.

2.1.2 Ball Clay "H"

An off-white (pinkish) moderately plastic clay which imparts green strength to a ceramic body. The clay, as supplied by Steetley Industries Ltd, was preground to minus 63 micrometres.

2.1.3 China Clay K371

A white non-plastic primary kaolin, supplied by Steetley Industries, preground to minus 63 micrometres.

2.1.4 Birdwood Clay K2

A white grit-free refractory clay low in plasticity, supplied by Minerals Pty Ltd, preground to minus 63 micrometres.

2.1.5 Axedale Ball Clay. Kaolin C/10

A moderately plastic grey, semi ball clay supplied by Minerals Pty Ltd preground to finer than 125 micrometres (10% coarser than 20 micrometres).

2.1.6 Alumina

Calcined alumina supplied by Comalco Aluminium Ltd. Nominal fineness 63 micrometres.

2.1.7 Potash Feldspar 200F

Potash feldspar marketed by Steetley Industries Ltd milled nominally to finer than 75 micrometres.

2.1.8 Silica

Marketed by Steetley Industries Ltd milled to finer than 75 micrometres.

Chemical analyses are given in Table 1.

2.2 Body Composition

Nine bodies were investigated with major components falling within the following compositional ranges (on a fired basis); SiO_2 48 to 65%; Al_2O_3 20 to 36%; MgO 9 to 12%. Under appropriate firing conditions all bodies were expected to produce a proportion of cordierite and to vitrify within the stoneware temperature range. Cordierite, $2MgO2Al_2O_35SiO_2$, contains 13.7% MgO, 34.9% Al_2O_3 and 51.4% SiO_2.

Calcined alumina was used in five of the bodies to increase their alumina content without increasing the silica content which is high in all clays and talc, and is particularly high in the plastic clays used in the study which were necessary to produce satisfactory casting properties. Excessive levels of silica in the bodies, over and above that required to produce cordierite and the associated silicate minerals formed during firing result in a body with free silica which may be deleterious to its thermal behaviour. Body compositions, and calculated chemical analysis, are given in Table 2.

2.3 Body Preparation

Bodies were prepared in porcelain jar mills, with distilled water at 65% solids concentration, with a charge of porcelain pebbles to effect mixing and dispersion. Bodies were milled for sufficient time, usually one half to one hour, to produce a fluid slip. Various quantities of sodium silicate and sodium silicate and sodium hexametaphosphate were added to the mills to obtain slips of favourable consistency. Final slip viscosities were adjusted after draining from the mills using a Brookfield Syncro Lectric Viscometer.

2.4 Slip and Casting Behaviour

Where possible slips were adjusted to between 5 and 35 poise viscosity for casting in plaster moulds. All bodies required high concentrations of deflocculants to obtain minimum viscosities at 65% solids and many of the slips showed marked thixotropy and an increase in viscosity over a period of hours. Addition of a small (0.05%) amount of sodium hexametaphosphate was, however, effective in again reducing viscosity to its previous level. Although time did not permit detailed investigation of the rheological behaviour of the slips it was noted that the slips did stabilize over a period of time with daily deflocculant doses to adjust the viscosity. As the slips stabilized they showed a lesser degree of thixotropy.

Only one of the slips (SCT1) could not be deflocculated satisfactorily for drain casting.

The properties of the various slips are summarized in Table 3.

Since only a preliminary investigation into the slip casting behaviour of the talc bodies was undertaken, casting rates were not studied in depth to determine the wall build up to time relationships for each slip. Therefore, a good casting rate, as exhibited by all except one of the castable slips examined, denotes in general a wall buildup of 3 to 4 millimetres in 12 to 20 minutes. SCT2, which showed rapid casting behaviour, produced a wall thickness of 6 millimetres in 5 minutes. With regard to the release properties of the various slips a satisfactory release was generally obtained within 30 minutes to 1½ hours without the aid of artificial drying.

3. TESTING OF CAST BODIES

Slips SCT4, 6, 8 and 9 showed good casting behaviour and samples were produced for firing trials.

Preliminary firing trials were undertaken on cast cups produced from each of the four slips at 1240 to 1260°C. Total firing times were three and a half hours with a one hour soak at each temperature. Sample SCT4 was fired over a range of temperatures from 1090°C to 1250°C to determine the effect of firing on mineralogy. Water absorption determinations were made on each fired product and on X-ray investigation of the mineral phases produced on firing was undertaken on selected samples.

4. RESULTS

Although some difficulty was initially experienced in casting the talc bodies it was found that satisfactory casting behaviour could be obtained from bodies incorporating up to 35% talc which, broadly, have chemical compositions favouring the development of cordierite on firing. Required deflocculant levels are high and repeated doses over a period of days were generally required to stabilize the slips.

The X-ray examination of sample SCT4 at various temperatures indicates that cordierite forms in minor amounts at least by 1200°C in association with other magnesium silicates, namely sapphirine and protoenstatite and cristobalite. Although the most appropriate formula for sapphirine is uncertain it approximates $Mg_7Al_{18}Si_3O_{40}$. Considerable substitution of Fe^{2+} for Mg may occur in addition to some AlAl⇌MgSi replacement.

With increasing temperature the cristobalite phase diminishes and is absent at 1250°C at which stage the fired material is composed predominantly of well-crystalline cordierite (indialite) with accessory amounts of sapphirine, mullite, protoenstatite and a trace of quartz.

At the lowest temperature examined, 1090°C-1110°C, abundant amorphous material is present with equal amounts of mullite, cristobalite, quartz and protoenstatite. With increasing temperature, and development of the crystalline phases, the proportion of amorphous material decreases.

Fired samples are strong at all temperatures and water absorptions decrease with increasing temperature from 11.6% at 1090°C - 1110°C to 0.26% at 1250°C. During firing samples distorted, at temperatures of 1175-1200°C and above, in thin walled products (3 millimetre thick).

Elimination of 10% feldspar from body SCT4 with an increase in the talc and clay components resulted in an increase in fired water absorption (Sample SCT6) to 4.7% at 1240°C-1270°C. However, most of the absorption was due to surface porosity of the sample which recorded a permeability of less than 0.1 millidarcys. The fired mineralogy consisted predominantly of cordierite with accessory cristobalite and traces of mullite, protoenstatite and quartz.

Substitution of the Ball Clay "H" in body SCT6 for Axedale ball clay in SCT8 resulted in an increase in the casting rate. The fired water absorption of the product remained similar.

By eliminating the alumina from body SCT8 and increasing the ball clay and china clay, resulting in a body of similar magnesium but higher silica and lower alumina content, a self glazing fully vitrified product was produced at 1260°C. X-ray diffraction showed that the product consisted of well crystalline cordierite with trace to accessory amounts of protoenstatite, cristobalite, quartz and mullite.

X-ray data and water absorption results are given in Table 4.

5. DISCUSSION

The preliminary work indicates that products consisting of a high proportion of cordierite may be produced from a number of talc, clay, alumina and feldspar mixtures which are readily slip cast in plaster moulds. Slips incorporating Gumeracha talc require high levels of deflocculant and generally exhibit a degree of instability, changes in viscosity and thixotrophic behaviour, over a period of days which may require attention to maintain uniform casting properties.

Results obtained indicate that porous (earthenware) and impervious (stoneware) products may be manufactured from talc bodies using cheap local materials and that ovenware products may be manufactured which contain a significant proportion of cordierite.

Distortion observed on firing in thin walled castings of Body SCT4 may be eliminated by increasing the wall thickness and maintaining a temperature slightly below 1250°C to produce a vitrified product.

Fired samples have been dispatched under separate cover.

dk:5.

TABLE 1: CHEMICAL ANALYSIS OF RAW MATERIALS

	Talc	Ball Clay "H"	China Clay K37L	K. Feldspar	Axedale Ball Clay C/1Q	Birdwood K2
SiO_2	61.2	65.6	45.4	67.0	61.02	54.3
TiO_2	0.16	1.2	0.4	-	1.50	1.7
Al_2O_3	1.51	20.5	38.0	18.0	24.6	38.3
Fe_2O_3	0.83	1.8	0.8	0.3	0.94	0.4
FeO	2.07	-	-	-	-	-
MnO	0.01	-	Tr	-	-	-
MgO	28.44	1.0	0.3	0.1	0.81	0.05
CaO	0.13	0.5	0.3	0.3	0.07	0.06
Na_2O	0.56	0.7	0.4	3.6	0.44	-
K_2O	0.06	2.4	0.4	10.3	3.13	0.01
P_2O_5	0.10	-	-	-	-	-
L.O.I.	4.7	6.2	13.6	0.4	7.63	13.8

TABLE 2: BODY COMPOSITIONS AND CALCULATED CHEMICAL ANALYSES (FIRED BASIS)

Body No. & Composition	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
SCT1 Talc 33% Birdwood Clay 67%	56.40	1.36	30.32	0.59	0.72	9.89	0.10	0.20	0.09	0.04
SCT2 Talc 40% Feldspar 10% Alumina 20% Bridwood Clay 30%	48.19	0.67	35.83	0.58	0.87	11.97	0.11	0.60	1.08	0.04
SCT3 Talc 40% Feldspar 10% Ball "H" 30% Alumina 20%	53.39	0.47	29.0	0.95	0.87	12.28	0.24	0.8	1.83	0.04
SCT4 Talc 30% Feldspar 10% "H" 24% Alumina 10% China 26%	56.43	0.49	28.99	0.98	0.65	9.31	0.27	0.85	1.80	0.03
SCT5 Talc 39.4% Feldspar 10.6% "H" 24% China 25%	62.87	0.51	19.74	1.04	0.85	12.11	0.29	0.92	1.86	0.04
SCT6 Talc 34.4% "H" 26.2% Alumina 10.9% China 28.5%	55.39	0.54	29.72	1.04	0.75	10.65	0.27	0.52	0.84	0.04
SCT7 Talc 35% Silica 10% Axedale 27% China 28%	65.04	0.64	20.06	0.82	0.76	10.77	0.15	0.48	1.08	0.04
SCT8 Talc 34.4% Alumina 10.9% Axedale 26.2% China 28.5%	54.38	0.62	30.96	0.82	0.75	10.59	0.16	0.46	1.23	0.04
SCT9 Talc 23.8% Axedale 23% China 35.2	60.72	0.76	24.54	0.93	0.71	10.18	0.18	0.52	1.28	0.04

TABLE 3: SUMMARY OF SLIP PREPARATION AND CASTING PROPERTIES

Body No. SCT	1	2	3	4	5	6	7	8	9
Sodium silicate %	*	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sodium hexametaphosphate %	*	0.4	0.27	0.2	0.1	0.225	0.2	0.3	0.2
Viscosity (poise)	*	35	30	8	4.5	7.6	7	6	7.5
Casting Rate	*	Rapid	Good	Good	Good	Good	Good	Good	Good
Drain	*	Fair	Clean	Clean	Clean	Clean	Clean	Clean	Clean
Release	*	Poor	Poor	Satisfactory 1 hour	Nil	Satisfactory 35 mins.	Poor	Satisfactory	Satisfactory
Defects	*	Cracked in mould.	Some sticking in mould. Cast soft.	-	-	-	Some sticking in mould	-	-

* Could not obtain satisfactory deflocculation.

TABLE 4: MINERALOGY AND WATER ABSORPTION OF FIRED SAMPLES

Body No./Firing Temp. °C	SCT4 1090°C to 1110°C	SCT4 1175°C to 1200°C	SCT4 1225°C	SCT4 1250°C	SCT6 1240°C to 1270°C	SCT9 1260°C
<u>Mineralogy</u>						
Cordierite/Indialite	-	Tr	Tr	D	D	D
Mullite	A	A	A	A	Tr-A	Tr
Cristobalite	A	D	A	-	A	A-Tr
Protoenstatite	A	A	A	A	Tr	Tr-A
Quartz	A	Tr-A	Tr-A	Tr	Tr	Tr
Sapphirine	-	A	A	A	-	-
Amorphous Material	Abundant	Present	Present	Present	-	Very minor
Water Absorption %	11.6	4.6	0.26	0	4.7	Vitrified

<u>Key</u>

D = Dominant (probably greater than 30%)

A = Accessory (probably 5-15%)

Tr = Trace (probably <5%)

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USES OF TALC/ALBITE ROCK

S.A. Department of Mines and Energy

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PROGRESS REPORT NO. 4

USES OF TALC/ALBITE ROCK

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1. INTRODUCTION

As an extension to the work already undertaken in relation to the utilization of 'Talc/Albite Rock' as a Ceramic Raw Material the Department of Mines & Energy requested that a commercially imported casting slip be investigated with the object of producing a similar slip from locally produced materials incorporating, in particular, talc/albite material.

The imported product known as Westwoods Clay Slip is manufactured in America and is extensively used throughout Australia by hobby ceramists. The particular product investigated is an earthenware body composition imported as a dry powder. The casting slip is prepared by addition of water and a product referred to as 'dope' (a deflocculating agent) to the dry powder.

A large range of pre mixed ceramic glazes are marketed for use with the Westwood's slip which have been formulated to 'fit' this particular body. It is generally considered by users of these products that the Westwood slip must be used with the special pre-mixed glazes and vice versa. The glazes are manufactured by Duncan Ceramic Products Inc, Fresno, California.

Suppliers of the clay slip recommend that the cast dry pieces are initially bisque fired at 1100°C followed by application of the glazes, generally by brushing, followed by a second firing to a temperature indicated in the instructions accompanying each glaze, usually Orton cone 06-05 (1015°C - 1040°C).

2. OBJECTIVES

The degree of control of slip characteristics exercised in a commercial production shop which may be required to manufacture thousands of identical pieces daily over a period of months or years is totally foreign to the operation of the hobby ceramist. For this reason the investigation described herein was approached with a relatively broad range of objectives which are considered to be of primary concern to the specific intended market. The object of the investigation was to produce a slip which :

a) Is readily manufactured from locally available components which maintain a reasonable degree of consistency over a period of time.

b) Has casting properties and behaviour comparable with Westwood's slip.

c) Has comparable firing behaviour to that of the Westwood's slip. Properties such as shrinkage, fired colour and absorption are regarded as being relevant although they need not necessarily be identical to similar properties of Westwood's slip.

d) When fired to 1100°C the resultant product has adequate strength and durability to be regarded as comparable to similar products cast from Westwood's slip.

e) After initial firing may be readily glazed with the Duncan range of glazes and after glost firing these glazes to provide a surface free of defects, in particular crazing, which is similar to the glaze finish obtained on a glazed Westwood body.

3. NATURE AND COMPOSITION OF WESTWOOD SLIP

A sample of the Westwood slip, as received, had a solids content of 68.5% and a viscosity in excess of 100 000 centipoise. An X-ray diffraction trace of a dried aliquot of the slip and of a less than 2 micrometre size fraction, which constituted 39% of the bulk material, indicated the following components to be present.

Component	Relative Proportion Bulk Material	 Less than 2 Micrometre Fraction
Talc	D	SD
Quartz	SD	Tr
Kaolin	SD	D
Calcite	A	
Muscovite	A	Tr-A
Dolomite	Tr-A	
Amphibole ?	Tr	Tr

<u>Legend</u>

D	Dominant
SD	Sub-dominant (15-30%)
A	Accessory (5-15%)
Tr	Trace (<5%)

The slip was grey in colour and thickly gelled. Agitation was ineffective in reducing the viscosity of the slip.

4. INVESTIGATION OF ALTERNATIVE SLIPS

4.1 Materials

4.1.1 Talc T'2

Jarvind Super-fine preground to minus 75 micrometres, as supplied by Minerals Pty Ltd. The material consists of predominantly talc with 5% of albite (sodium feldspar), a trace of dolomite and possibly quartz. Colour is yellowish.

4.1.2 McLaren Vale White

A plastic siliceous off-white clay containing approximately equal proportion of kaolinite and muscovite and a trace of potash feldspar. The clay fires to a hard pale yellowish grey product at 1100°C with an absorption of approximately 9%. The material, supplied by Clay & Mineral Sales Pty Ltd, was ground to minus 200 mesh (75 micrometres) B.S. for incorporation in casting bodies.

4.1.3 Ball Clay 'H'

An off-white moderately plastic clay, supplied by Steetley Industries Ltd, preground to minus 63 micrometres.

4.1.4 Axedale Ball Clay. Kaolin C/IQ

A moderately plastic, grey, semi ball clay supplied by Minerals Pty Ltd preground to finer than 125 micrometres (10% coarser than 20 micrometres).

4.1.5 Whiting

A preground yellowish limestone of 75 micrometres fineness.

4.1.6 Potash Feldspar

A pinkish, potassium feldspar from Broken Hill marketed by Steetley Industries Ltd milled nominally to finer than 75 micrometres.

4.1.7 Talc T1

First grade white talc marketed by Minerals Pty Ltd milled to minus 53 micrometres (2% retained).

Chemical Analyses are given in Table 1.

4.2 Experimental Procedure & Results

4.2.1 Preparation of Slips

The viscosity of the Westwoods slip was reduced by addition of distilled water until a satisfactory consistency was attained. Nine alternative slips were prepared based upon the mineralogical analysis of the Westwood slip, the known behaviour of the individual slip components and progressive data obtained during the investigation. Compositions are given in Table 2.

Each slip was prepared by blunging the dry components in distilled water to which 0.6% of liquid sodium silicate, based upon the dry weight of the body components, had been added. Final adjustments to the degree of deflocculation of the slips, where required, was effected by additions of sodium hexametaphosphate (Calgon) during blunging. All slips were prepared at 65% solids content and allowed to stand for 30 minutes prior to testing.

4.2.2 Viscosity Determinations

After standing the slips were stirred prior to measuring their viscosity using a Brookfield Syncro Lectric Viscometer fitted with a No. 3 spindle at shear rates of 10, 20, 50 and 100 rpm to determine the relationships of shear stress to rate of shear.

Two of the slips proved unsatisfactory at this stage due to excessive viscosities and were eliminated from the testing programme. Results obtained from the remaining seven test slips plus the standard Westwoods slip are shown in Table 3 and Graphs 1 and 2.

4.2.3 Casting Behaviour

Slips were cast in plaster moulds for 25 minutes prior to draining for 15 minutes. All slips showed good casting and clean draining behaviour and although slight variations in casting rate were noted measurements of wall buildup were not recorded since this property varies extensively depending upon a large number of parameters which differ from one cast shop to another. All slips however showed comparable behaviour to the Westwood's slip under similar casting conditions (wall thickness measured after stripping generally ranged from 4 to 4.5 mm).

When cast in a relatively dry mould (5-10% moisture) all slips released within 1 hour and casts were sufficiently rigid for stripping and trimming with 1½ hours of casting.

4.2.4 Drying & Firing

Green casts were air dried for 12 to 24 hours after stripping followed by severe drying at 105°C for 24 hours. Dry casts were strong, hard and readily handled without sustaining damage.

The casts were bisque fired in an electric kiln to 1100°C over a 7 hour period including a 1 hour soak on peak temperature. Drying and firing shrinkages, together with 24 hour cold water absorption and fired colour results are shown in Table 4.

4.2.5 Glazing

Four Duncan E-Z flow ceramic glazes were applied to the fired products which were re-fired to 1040°C over a 6½ hour firing cycle including a one hour soak on peak temperature.

The glazes used were: Opaque White GL-638, Walnut Brown GL-666, Royal Blue GL-634 and Bottle Green GL-669. No glaze defects which are attributed to poor 'fit' of body and glaze were observed on the fired products.

Once fired glazed ware, fired to 1100°C also performed satisfactorily.

4.2.6 Resistance to Crazing

A glazed product manufactured from each of the seven test slips, and from the Westwoods slips, was immersed in steam at a pressure of 690 kN/m² (100 psi) for 2 hours in accordance with the procedure recommended for determining the crazing resistance of glazed ceramic tiles (BS 1281:1974 Specification for Glazed ceramic tiles and tile fittings for internal walls).

As shown in Table 5 glazes on two of the experimental bodies (Nos 6 & 7) either crazed or developed fine hairline cracks as a result of the test. These bodies contained the highest percentage of potash feldspar, 10% and 15% respectively. The crazing observed in these glazes is a result of moisture expansion of the bodies which will occur gradually when the glazed ware is in service, although the time lapse will depend upon the imposed conditions. The steam pressure test accelerates the rate of crazing.

If the porosity of the body is to remain relatively the same crazing, resulting from moisture expansion, may be prevented by increasing the amount of silica and sometimes lime and magnesia content of the body. Reference to Table 2 indicates that in all of the bodies cast the lime and/or magnesia content of the bodies which do not show glaze crazing as a result of moisture expansion is considerably higher than that of bodies 6 and 7 which do show crazing. Further supportive evidence of the effect of an increased lime content in a body as a prevention against glaze crazing as a result of moisture expansion is shown by the degree of crazing on body 7 which contains no lime but a high potash content compared with body 6 which contains lime and consequently shows a lesser affinity for glaze crazing.

5. DISCUSSION

Of the nine slips investigated five may be considered as potential substitutes for the Westwoods slip. These slips, numbers 1, 3, 5, 8 and 9 may be readily manufactured from locally available materials, have good casting properties, fire satisfactorily and are compatible with the Duncan glazes.

Of these five slip number 1 has the highest casting viscosity and a higher yield point (see Graph 2) than the remaining slips and this could, under some circumstances, reduce its usefulness. Consideration must be given to the market proposed which is not acquainted with many factors such as slip temperature and salt content of make up water which will further increase the viscosity and yield point of the slip resulting in variation in the properties and behaviour of the slip. This body is therefore assigned a low priority.

On the basis of fired properties all of the remaining bodies have total shrinkages of 5% to 6%, considerably lower than the Westwoods slip (10.5%). In particular the firing shrinkages of the experimental bodies are very low, approximately 1% compared with 4% for Westwoods slip. Water absorption of the fired products are generally double that of the Westwoods slip, however, this factor is not regarded as detrimental since all slips develop adequate strength for their intended market, exhibit a sharp sound ring, and do not show crazing due to moisture expansion.

The fired colour of the four potential slips may be used as a determining selective factor in which case bodies 5 and 9 are distinctly less pinkish than bodies 3 and 8, and may therefore be preferred. The pinkish discolouration of the latter bodies is attributed to the higher iron content of the T'2 talc compared with T1 talc.

6. CONCLUSIONS

Earthenware slips incorporating talc/albite material may be readily manufactured from locally available materials to produce slip cast bodies which have comparable casting behaviour to the Westwoods clay slip and are compatible with the Duncan glazes examined.

Slips identified as numbers 3, 5, 8 and 9 could be used as substitutes for the Westwoods slip and for comparative purposes the following properties are summarized :

a) Casting at 65% solids, when adequately deflocculated, the experimental slips will cast, release and develop green strength properties comparable to Westwoods slip.

b) Drying and firing shrinkages of the experimental slips will be less than those of the Westwood slip and total shrinkages will be 4% to 5% less than that of the Westwood slip when cast under similar conditions and fired to 1100°C.

c) The water absorption of the experimental bodies will be higher than the absorption of the Westwood slip body. However, the increased degree of absorption has not been shown to be deleterious to the bodies and should not affect their in-use behaviour for the general hobby ceramic field.

d) The fired colour of the experimental bodies will be either cream or pinkish when compared with the white Westwood body. This difference could be eliminated by selecting raw materials of greater purity (containing less iron).

e) Some variations in glaze colours may be apparent between the various bodies particularly when thin glaze coatings are applied. Less overall variation may be apparent on the whiter bodies, numbers 5 and 9, than on bodies 3 and 8 when compared with a similar glaze on a Westwood body.

Samples of both glazed and unglazed bodies are being supplied.

dk:6.

TABLE 1: CHEMICAL ANALYSIS OF SLIP MATERIALS

	Talc T'2	McLaren White	Ball Clay 'H'	Kaolin C/IQ	K Feldspar	Talc T1
SiO_2	61.2	69.40	65.6	61.02	67.0	63.6
Al_2O_3	1.51	23.64	20.5	24.6	18.0	0.38
Fe_2O_3	0.83	1.37	1.8	0.94	0.3	0.36
FeO	2.07	0.05				0.56
MgO	28.44	0.43	1.0	0.81	0.1	29.7
CaO	0.13	0.47	0.5	0.07	0.3	0.12
MnO	0.01	0.01				
Na_2O	0.56	0.22	0.7	0.44	3.6	0.07
K_2O	0.06	1.55	2.4	3.13	10.3	0.04
TiO_2	0.16	2.20	1.2	1.50		0.03
P_2O_5	0.10	0.04				
SO_3		0.08				
Cl		0.06				
CO_2		0.32				
L.O.I.	4.7		6.2	7.63	0.4	5.27

TABLE 2: COMPOSITIONS OF EXPERIMENTAL SLIPS

Slip No.	Composition %							Deflocculant
	Talc T'2	McLaren White	Talc T1	Ball Clay 'H'	Axedale Ball Clay	K Feldspar	Whiting	
1	35	50					15	0.6% sodium silicate 0.2% calgon
2	30	45				10	15	0.6% sodium silicate
3	35			50			15	0.6% sodium silicate
4	35				50		15	0.6% sodium silicate
5			35	50		5	10	0.6% sodium silicate
6			30	50		10	10	0.6% sodium silicate
7			35	50		15		0.6% sodium silicate
8	30			50		5	15	0.6% sodium silicate
9			35	50			15	0.6% sodium silicate

TABEL 3: VISCOSITY DETERMINATIONS

Slip	Shear Stress/Viscosity (cps) 1	3	5	6	7	8	9	Westwoods
Rate of shear(s) rpm								
10	29.5/2950	12/1200	13.5/1350	9.5/950	18.5/1850	6.2/620	9.2/920	19/1900
20	42/2100	19/950	21/1050	15/750	28/1400	10/500	15/750	28/1400
50	68/1360	35/700	36.5/730	27/540	47/940	18.8/376	29/580	41/820
100	100+/1000+	58/580	58/580	43/430	72.5/725	33/330	49/490	56.5/565

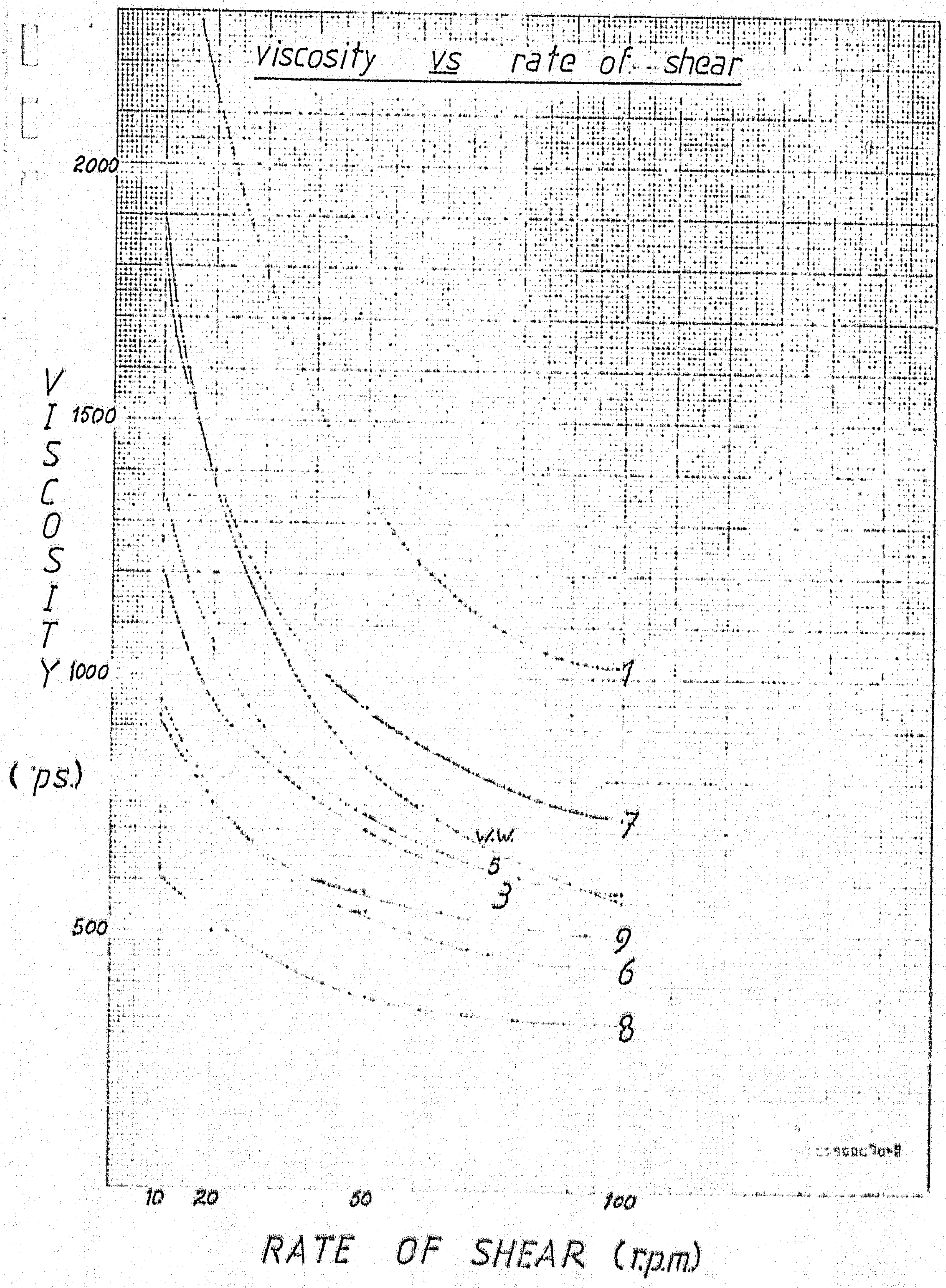
TABLE 4: SHRINKAGE & ABSORPTION RESULTS

Slip	Drying Shrinkage %	Firing Shrinkage %	Total Shrinkage %	Water Absorption %	Fired Colour
1	3.7	2.3	6.0	18.7	Pink
3	5.0	1.0	6.0	19.2	Pink
5	4.3	0.7	5.0	16.7	Green/white
6	5.0	1.0	6.0	16.1	Cream
7	6.3	0.5	6.8	10.6	Pink/cream
8	3.8	1.1	4.9	15.0	Pink/cream
9	5.3	0.7	6.0	15.8	Cream
Westwoods	6.4	4.1	10.5	7.7	White

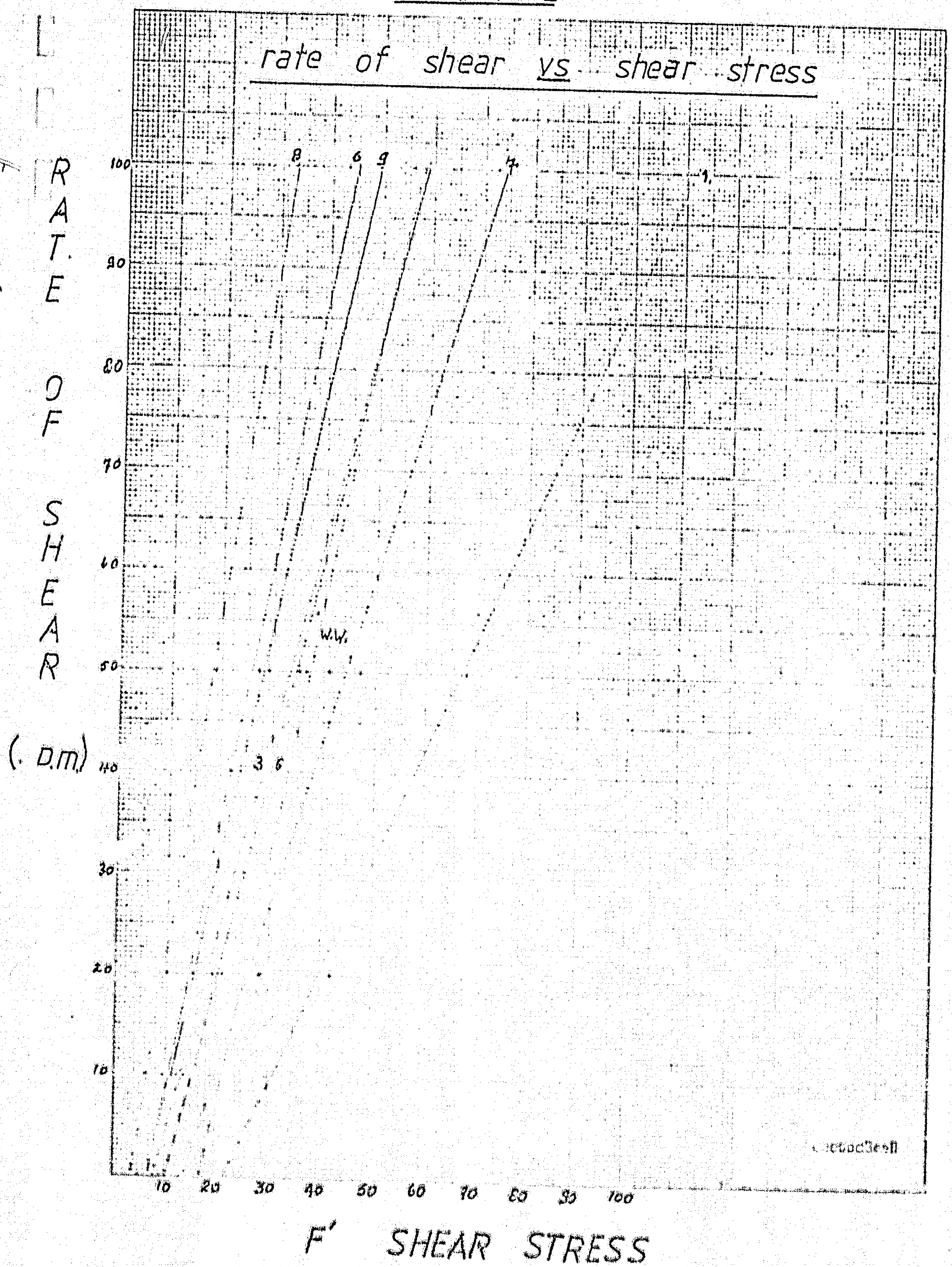
TABLE 5: CRAZING RESISTANCE

Slip	
1	No crazing or cracking
3	No crazing or cracking
5	No crazing or cracking
6	Crazing of blue glaze. Slight hairline cracking of remaining 3 glazes
7	Extensive crazing of all glazes
8	No crazing or cracking
9	No crazing or cracking
Westwoods	No crazing or cracking

GRAPH 1


viscosity vs rate of shear
VISCOSITY
(ps.)
2000
1500
1000
500
10
20
50
100
RATE OF SHEAR (r.p.m.)
1
7
W.W.
5
3
9
6
8

GRAPH 2


rate of shear vs shear stress
RATE OF SHEAR
(. D.m)
F' SHEAR STRESS
8
6
9
7
1
W.W.
3
6
100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100

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Amdel Report

No. 1300

USES OF TALC/ALBITE ROCK

by

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SUMMARY

Background

Extensive deposits of talc exist in the Gumeracha-Lyndoch area of South Australia about fifty to one hundred kilometres north-east of Adelaide. Much of the talc contains significant feldspar, 5-30%. Project investigations have been carried out by AMDEL for the S.A. Department of Mines and Energy to identify possible markets for this talc. This report is specifically directed towards uses of the talc/albite rock, without beneficiation or chemical treatment. A previous investigation, AMDEL Report No. 1235, described the successful development of talc-based vitrified floor tiles.

Objectives

The primary objective of this investigation was to determine uses for talc/albite rock. Secondary objectives were to determine its uses for manufacture of certain ceramic products namely refractories, ovenware and casting slip for hobby ceramics.

Summary of Work Done

Ceramic bodies utilizing talc, talc/albite and local ceramic materials where possible were developed. Products were evaluated against typical design criteria to establish the potential for these bodies.

Conclusions

Talc/albite rock from Gumeracha/Lyndoch was shown to have specific uses in relation to :

1. Production of high thermal shock refractories suitable for use up to 1300°C or so. This material has application for kiln doors, hearths, furniture, fast-firing saggars et cetera.
2. Production of oven- and cook-ware such as casseroles, pie-dishes, and, possibly, skillets.
3. Production of casting slips similar in casting, firing and glazing properties to currently imported lines.

1. INTRODUCTION

Investigation into the utilization of low grade talc mined in South Australia specifically for use in the ceramic industry has been undertaken of a period of years. This work, sponsored by the South Australian Department of Mines and Energy, followed from previous investigations initially designed to evaluate, assess and characterize the large number of talc deposits within South Australia.

Large deposits of impure talc exist, and are presently mined, in the Gumeracha and Lyndoch-Truro areas of South Australia and it is these deposits, and more specifically the Gumeracha deposits, which have been extensively evaluated for a variety of industrial ceramic uses over the last three years at Amdel.

Much of the talc mined from these areas is relatively unique in that the talc is associated with the feldspar, albite. The albite occurs both as massive material within the talc bodies and as finely dispersed material intimately associated with the talc.

Drilling undertaken by the South Australian Department of Mines and Energy indicates that although the percentage of albite within the Gumeracha deposit may vary between 5 and 30% throughout the deposit relatively large tonnages may be extracted with a consistent level of feldspar.

Further to the feldspar impurity, the majority of the talc is iron stained in the Gumeracha area and although hand picked material of first grade quality may be obtained, any large mining operation will result in production of second to fourth grade material. The grade classification depending primarily upon the colour of the talc. Ground material of third grade quality is generally yellowish to pink in colour, fourth grade material being more extensively stained.

Thus the association of both albite and iron discolouration, due possibly to both ferric and ferrous iron in the talc, downgrades the value of the overall deposits considerably and many of the higher prised markets, traditionally the cosmetic and some filler applications, are unattainable for the majority of the talc readily available to open cut mining.

Two possibilities thus exist, either the area of beneficiation be considered to upgrade the colour of the lower grade material, possibly with concurrent recovery of feldspar, or uses for the talc-albite material are more widely considered.

Although only a limited amount of work has been undertaken in relation to improving the colour of the talc results tend to suggest that to a degree the discolouration of the talc is due to ferrous iron substitution within the talc lattice. If this is proven to be correct then significant improvements in the colour of the talc may not be attainable.

The material association of the talc and albite has obvious advantages in the ceramic industry where feldspar and talc are often used as fluxing materials and talc itself as a major body component. For this reason it was considered that a major market opening could be found for Gumeracha talc in a number of ceramic industries particularly if higher valued products, such as tiles and refractories, could be manufactured.

A previous Amdel Report No. 1235, titled 'Manufacture of Talc-Based Tiles', outlines the successful development of a fast-firing tile body incorporating seventy percent of third grade Gumeracha talc,containing approximately 25% of albite, with thirty percent of a locally available plastic clay. The most recent work, reported herein, summarizes three additional development projects to further extend the ceramic uses of the natural talc-albite material, namely.

a) Production of cordierite refractories
b) Development of slip cast,cordierite developing bodies
c) The development of a slip casting body with specific properties and suitability for a range of imported glazes used in the hobby ceramic field

Four progress reports titled 'Uses of Talc/Albite Rock, Progress Reports Nos 1-4, Amdel Project MD 1/1/228, have hitherto been issued.

2. CORDIERITE

Cordierite, 2MgO $2Al_2O_3$ $5SiO_2$, contains 13.7% MgO, 34.9% Al_2O_3 and 51.4% SiO_2. In nature it is found in granites, gneisses, schists and in contact metamorphic zones. Industrially it is manufactured from talc, kaolinite, magnesia and alumina. Segnit & Holland(1971) investigated the use of clinochlore, a chlorite of composition Mg_5 $Al_2Si_3O_{10}(OH)_8$, and a good quality kaolinite for manufacturing cordierite which began to form at temperatures as low as 1140°C associated with cristobalite and mullite phases. With increasing temperature these phases were eliminated resulting in only cordierite at 1225°C. Geller & Insley (1932) produced porous cordierite bodies, with high thermal shock resistance and low thermal expansion, from bodies consisting of talc, kaolin and corundum (or calcined alumina) at temperatures of 1350°C and showed that an increase in cordierite was directly responsible for a decrease in thermal expansion. Numerous other workers have also investigated various talcs and clays for producing cordierite, generally at temperatures above 1300°C. Theiss (1943) studied the formation of vitrified cordierite bodies in systems containing feldspar, beryl, spodumene, nepheline-syenite and feldspar-zinc oxide combinations to evaluate their effect on extending the firing range of vitrified products. Generally cordierite bodies have short virtifying ranges which creates problems in industrial manufacturing and as early as 1930 in Germany, alkalies, iron oxides and red-firing clays were added to cordierite insulator mixes to extend their firing ranges.

Data produced by Theiss shows that feldspar, nepheline-syenite and feldspar-zinc oxide used as a flux in vitrified cordierite bodies did extend their vitrification firing ranges.

It is well established that cordierite may form at different temperatures depending upon the physical and chemical properties of the constituents. For example, the work previously mentioned of Segnit and Holland produced a body of only cordierite composition at 1225°C and a well crystallised cordierite with minor mullite and cristobalite phases at 1200°C using clinochlore and kaolinite.

Presumably because the chlorite and kaolinite undergo major structural breakdown at temperatures below 1000°C, the resulting disordered structures are favourable for the early development of stable phases. However, in the case of talc, kaolinite and alumina combinations investigated by Hughan (1952) and the kaolinite, magnesia and silica or, alumina, magnesite and silica bodies investigated by Jelasic and Kacian (1967) temperatures above 1300°C were necessary to form cordierite.

Takker et al (1974) studied the production of a dense-sintered monomineralic cordierite body using finely dispersed glass powders and raw clay. They report that X-ray photographs taken at 900°C show that the diffraction peaks of cordierite are clearly developed. Between 1100°C and 1450°C this becomes the unique crystal phase. The process whereby an initial crystal phase is completely transformed into cordierite is complete at 1100°C. This is in contrast to cordierite development in traditional bodies, as already mentioned, where cordierite does not begin to form below temperatures of approximately 1150°C.

Thus cordierite may be synthesised relatively easily from a variety of materials by selecting components and blending them in the amount required by the stoichiometric formula of cordierite. This uncomplicated procedure is, however, only partially satisfactory since the completeness of the reaction and mineralogy of the final product is dependent upon the firing temperature and soak times, the fineness of the components, the decomposition and the degree of reactivity of the components. Additional variables have been found to be of relevance, such as the presence of fluxes and mineralizers to extend the sintering range and promote self glazing of vitrified products and the additional of excess alumina to broaden the firing range and reduce the thermal expansion of a cordierite body (Basta and Said 1973).

3. CORDIERITE REFRACTORY DEVELOPMENT

3.1 Materials

3.1.1 Talc T/2

The talc was a 3rd grade yellowish-pink material (minus 200 mesh) designated as Jarvind Super-Fine T/2, preground to minus 75 micrometres supplied by Jarvis Industries Pty Ltd.* Analysis by X-ray diffraction shown in Table 1 indicated dominant talc with approximately 5% of albite and a trace of dolomite. A possible faint trace of quartz, outside the limit of estimation, was indicated. The chemical analysis given in Table 1 indicates a soda content of 0.56%, confirming the albite estimation, and a 0.13% level of calcium which may be attributed to dolomite. Ferric and ferrous oxides account for 2.9% of the composition. If the talc were of ideal composition then the magnesium would account for 57% of the silica leaving an excess of approximately 4% of which 3.3% may be attributed to the albite and the remainder to excess silica.

A dry screen size analysis is given in Table 2.

3.1.2 Williamstown Sillimanite Clay

A high alumina refractory clay from Williamstown in South Australia containing approximate equal proportions of kaolinite and sillimanite and sub-dominant (15-30%) mica (muscovite and paragonite). Accessory quartz estimated at between 5 and 15% is present together with a trace of pyrophyllite (<5%). The clay is non-plastic, white in colour, and contains 0.5% ferric iron, 43.4% Al_2O_3, 44.3% SiO_2, 1.36% TiO_2, 0.52% Na_2O (attributed to paragonite) and 1% K_2O (muscovite). The clay was preground to a nominal fineness of 600 micrometres (25 mesh B.S.S.) A complete analysis is shown in Table 1.

3.1.3 Birdwood Refractory Clay

A white refractory china clay preground to 63 micrometres (250 mesh B.S.S.) supplied by Minerals Pty Ltd. The clay is basically free from fluxing oxides and contains 38% Al_2O_3 and 45% SiO_2. A chemical analysis is given in Table 1.

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*Company now Minerals Pty Ltd

3.2 Body Compositions and Preparation

A 1:3 molar mix of talc and each individual clay was chosen for the composition of the experimental cordierite bodies (32.8% talc:67.2% clay). Using the Williamstown clay, the mix thus contains primarily 10% MgO, 32% Al_2O_3 and 53% SiO_2 on a fired basis corresponding to a formulation MgO:1.24 Al_2O_3:3.5 SiO_2. Theoretical cordierite contains 13.6% MgO 35% Al_2O_3 and 51.4% SiO_2 (MgO:Al_2O_3:2.5 SiO_2).

With Birdwood Clay the mix contains 9.8% MgO, 30% Al_2O_3 and 56% SiO_2 corresponding to a formulation MgO:1.2 Al_2O_3:3.8 SiO_2.

Mixes incorporating the Williamstown clay were wet milled to produce bodies of various fineness for pressing into tiles, firing and subsequent evaluation. Samples of the Birdwood talc/clay body were produced by extrusion.

3.3 Firing and Testing Procedures

Samples were fired in both electric and gas kilns at temperatures ranging from 1250°C to 1400°C with firing cycles varying from 4½ hours including a 1 hour soak to a 3 hour cycle including a 2 hour soaking period.

The fired products were analysed by X-ray diffraction techniques and physical properties such as bulk density, apparent porosity, water absorption, firing shrinkage and modulus of rupture were determined.

Details of mixes, firing conditions and fired properties are given in Table 3.

3.4 Mineralogical and Physical Properties of Fired Products

All fired products consisted predominantly of indialite (Miyashiro 1957), the hexagonal polymorph of cordierite in association with sillimanite, in the Williamstown clay bodies, and a trace of quartz. Protoenstatite is present in some products up to 1310°C.

3.4.1 Fine Grained Bodies - Less than 75 micrometres (Talc/Williamstown Clay)

A 1250°C sample was not produced but at 1270°C highly crystalline indialite is well developed in association with an accessory amount of remanent sillimanite and traces of protoenstatite and quartz. With an increase in temperature to 1290°C the protoenstatite reacts with alumina to form indialite. The remaining crystalline phases appear to maintain their relative proportions. The bodies produced are hard, dense and near vitrified at 1290°C at which temperature a very thin glaze was detectable on the surface. Notable distortion was evident at 1310°C and a heavy glaze was well developed.

3.4.2 Bodies Finer Than 300 Micrometres (Talc/Williamstown Clay)

Highly crystalline indialite is well developed at 1250°C in association with quartz, protoenstatite and remnant sillimanite. With increasing temperature up to 1370°C indialite increases in relative proportion and sillimanite decreases. Protoenstatite is present up to 1310°C in trace amounts and quartz (2-3%) persists throughout the firing cycle.

Generally the degree of crystallinity of the indialite was not found to vary significantly with higher firing temperatures.

The fired products were strong, crystalline and porous ranging in colour from off-white at 1250°C to greyish at 1340°C and tan at 1400°C. Firing shrinkage, water absorption (2 hr boil) apparent porosity and bulk density results shown in Table 3 indicate an initial decrease in water absorption from 13.4% at 1250°C to 4.4% at 1340°C followed by an increase to 10.3% at 1400°C. Firing shrinkages range from 2.1% to 2.5% with the exception of the 1340°C samples which recorded a 3.2% firing shrinkage. The absorption and shrinkage results are consistent with an increase in bulk density at this temperature from an average at other temperatures of 1.99 (range 1.97 - 2.02) to 2.13 and a significant reduction in the apparent porosity of the body from 22.9% at 1310 to 9.7% at 1340°C. Above 1340°C the fired tiles show an increase in surface porosity. Examination suggests that a localized sintering process takes place. Pores or vesicles develop throughout the bodies surrounded by a yellowish crystalline halo.

Modulus of rupture results were limited to one determination at each temperature and are therefore regarded with caution. However, the results are in general agreement with other physical parameters already considered and the highest strength recorded of 34 MPa at 1340°C appears to verify that an increased rate of sintering does occur in the range of 1340°C with a subsequent reduction in porosity and water absorption and increase in the shrinkage and bulk density of the body. Above 1340°C the decrease in strength is considered to be attributed to the increased porosity of the body and resultant discontinuity of the mineral grains.

3.4.3 Coarse Grained Body (Talc/Williamstown Clay)

The clay component of the body contains a large proportion of sillimanite (approximately 35%), an extremely hard and tough mineral. It is, therefore, this mineral which forms the bulk of the 20% of plus 300 micrometre material in the body.

Firing in an electric kiln produced crystalline porous products ranging in colour from cream at 1250°C to light brown at 1340°C and a grey speckled product at 1370°C.

Compared with the finer grained (-300 micrometre) gas fired body, water absorptions, porosities and bulk densities are of the same general order for all temperatures between 1250°C and 1370°C (a 1400°C sample was not fired) with the exception of the 1340°C sample. At this temperature the body did not sinter to the degree observed in the finer grained sample and its behaviour was a significant reversal showing an increase in water absorption, apparent porosity and decrease in bulk density.

Shrinkages for the coarser body were higher at 1250°C than for the finer grained body but decreased with firing temperature to a minimum of 1.6% at 1340°C followed by a slight increase to 1.73% at 1370°C accompanied by a decrease in water absorption and apparent porosity and an increase in bulk density.

At 1340°C and 1370°C the surface porosity as noted in the minus 300 micrometre bodies became pronounced, particularly at the higher temperature, which is attributed to melting of discrete mineral grains. A distinct orange-red mineral, unidentified at this stage, was observed within some of the larger vacuoles surrounded by the yellowish crystalline halo.

The 1280°C and 1310°C samples, refired at 1280°C for 7 hours including a 3½ hour soaking period, recorded a slight expansion of 0.2% on refiring and a very minor reduction in their water absorption (2 hour boil).

3.4.4 Talc/Birdwood Clay Body

Firing at 1250°C produces a high strength porous, greyish-yellow product with a water absorption of 2.4%. An X-ray diffraction trace indicated that highly crystalline indialite is the dominant crystalline phase with a trace of protoenstatite, mullite and quartz. At 1350°C the material transforms into a greenish-black, molten, low viscosity mass.

4. DISCUSSION - CORDIERITE REFRACTORY BLENDS

The investigation has shown that synthetic indialite is readily produced from a combination of 32.8% Gumeracha talc, containing 5% albite, and 67.2% of high alumina Williamstown clay during fast firing cycles at temperatures as low as 1250°C. The indialite shows a high degree of crystallinity at all temperatures which does not appear to vary significantly over the range of temperature and time conditions imposed.

Increased firing temperature and soaking time alters the mineralogy of the fired samples within a series (constant particle size). Broadly, with increasing temperature, indialite increases in proportion and sillimanite decreases marginally. Protoenstatite disappears with increasing temperature and was not detectable above 1310°C. However, its presence or absence in the fired product is also dependent upon soaking time and fineness of the mix components.

In very fine grained samples protoenstatite was not detected at 1290°C but in coarser particle sized samples, produced from cycles with shorter soaking times, it persists to a higher temperature. Protoenstatite disappeared upon refiring the 1280°C coarse grained sample at the same temperature with a soak of 3½ hours.

The particle size of the mineral components of the mix is the most significant controlling factor on the type and nature of the fired product. Fine grinding of mineral components produces dense vitrified (or low absorption) products at 1270°C but coarser ground samples remain porous up to at least 1400°C when fast firing cycles are used.

The combination of talc and Birdwood clay examined lacks the refractory properties of the talc and Williamstown clay body. However, the association of high strength and a substantially cordieritic mineralogy at 1250°C implies that ceramic articles may be manufactured suitable for applications which demand both strength and low thermal expansion. (The latter property is only assumed at this stage based upon the determined mineralogy).

5. SLIP CAST CORDIERITE BODIES

A second phase of development relating to cordierite production was directed toward the manufacture of slip cast cordierite bodies which may be suitable for the production of stone and earthenware products in general and more specifically for ovenware.

Ceramic ovenware was considered since the previous work has shown that simple talc-clay bodies, incorporating local materials, readily produce cordierite (indialite) at the normal stoneware firing temperatures (1250°C - 1300°C). Bodies incorporating a percentage of cordierite exhibit a lower coefficient of thermal expansion than normal stoneware bodies in which cordierite is absent and thus they show superior heat-shock resistance, an important characteristic of quality ovenware bodies.

5.1 Materials

In addition to the talc and Birdwood Clay previously used a range of china clays, ball clays, alumina, feldspar and silica were used in specific bodies.

The additional materials were :

5.1.1 Ball Clay 'H'

An off-white (pinkish) moderately plastic clay which imparts green strength to a ceramic body. The clay, as supplied by Steetley Industries Ltd, was preground to minus 63 micrometres.

5.1.2 China Clay K37L

A white non-plastic primary kaolin, supplied by Steetley Industries, preground to minus 63 micrometres.

5.1.3 Axedale Ball Clay. Kaolin C/1Q

A moderately plastic grey, semi ball clay supplied by Minerals Pty Ltd preground to finer than 125 micrometres (10% coarser than 20 micrometres).

5.1.4 Alumina

Calcined alumina supplied by Comalco Aluminium Ltd. Nominal fineness 63 micrometres.

5.1.5 Potash Feldspar 200F

Potash feldspar marketed by Steetley Industries Ltd milled nominally to finer than 75 micrometres.

5.1.6 Silica

Marketed by Steetley Industries Ltd milled to finer than 75 micrometres.

Chemical analyses are given in Table 4.

5.2 Body Composition and Preparation

Nine bodies were investigated with major components falling within the following compositional ranges (on a fired basis); SiO_2 48 to 65%; Al_2O_3 20 to 36%; MgO 9 to 12%. Under appropriate firing conditions all bodies were expected to produce a proportion of cordierite and to vitrify within the stoneware temperature range.

Calcined alumina was used in five of the bodies to increase their alumina content without increasing the silica content which is high in all clays and talc, and is particularly high in the plastic clays used in the study which were necessary to produce satisfactory casting properties. Excessive levels of silica in the bodies, over and above that required to produce cordierite and the associated silicate minerals formed during firing, result in a body with free silica which may be deleterious to its thermal behaviour. Body compositions, and calculated chemical analysis, are given in Table 5.

Bodies were prepared in porcelain jar mills, with distilled water at 65% solids concentration, with a charge of porcelain pebbles to effect mixing and dispersion. Bodies were milled for sufficient time, usually one half to one hour, to produce a fluid slip. Various quantities of sodium silicate or sodium silicate and sodium hexametaphosphate were added to the mills to obtain slips of favourable consistency. Final slip viscosities were adjusted after draining from the mills using a Brookfield Syncro Lectric Viscometer.

5.3 Slip and Casting Behaviour

Where possible slips were adjusted to between 5 and 35 poise viscosity for casting in plaster moulds. All bodies required high concentrations of deflocculants to obtain minimum viscosities at 65% solids and many of the slips showed marked thixotropy and an increase in viscosity over a period of hours. Addition of a small (0.05%) amount of sodium hexametaphosphate was, however, effective in again reducing viscosity to its previous level. Although time did not permit detailed investigation of the rheological behaviour of the slips it was noted that the slips did stabilize over a period of time with daily deflocculant doses to adjust the viscosity. As the slips stabilized they showed a lesser degree of thixotropy.

Only one of the slips (SCT1) could not be deflocculated satisfactorily for drain casting.

The properties of the various slips, SCT1-9, are summarized in Table 6.

Since only a preliminary investigation into the slip casting behaviour of the talc bodies was undertaken, casting rates were not studied in depth to determine the wall build up to time relationships for each slip. Therefore, a good casting rate, as exhibited by all except one of the castable slips examined, denotes in general a wall build up of 3 to 4 millimetres in 12 to 20 minutes. SCT2, which showed rapid casting behaviour, produced a wall thickness of 6 millimetres in 5 minutes. With regard to the release properties of the various slips a satisfactory release was generally obtained within 30 minutes to 1½ hours without the aid of artificial drying.

5.4 Firing and Testing of Cast Bodies

Slips SCT4, 6, 8 and 9 showed good casting behaviour and samples were produced for firing trials.

Preliminary firing trials were undertaken on cast cups produced from each of the four slips at 1240 to 1260°C. Total firing times were three and a half hours with a one hour soak at each temperature. Sample SCT4 was fired over a range of temperatures from 1090°C to 1250°C to determine the effects of firing on mineralogy. Water absorption determinations were made on each fired product and an X-ray investigation of the mineral phases produced on firing was undertaken on selected samples.

5.5 Results

Satisfactory casting behaviour was obtained from bodies incorporating up to 35% talc which, broadly, have chemical compositions favouring the development of cordierite on firing. Required deflocculant levels are high and repeated doses over a period of days were generally required to stabilize the slips.

The X-ray examination of sample SCT4 at various temperatures indicates that cordierite forms in minor amounts at least by 1200°C in association with other magnesium silicates, namely sapphirine and protoenstatite, and cristobalite.

With increasing temperature the cristobalite phase diminishes and is absent at 1250°C at which stage the fired material is composed predominantly of well-crystalline indialite with accessory amounts of sapphirine, mullite, protoenstatite and a trace of quartz.

At the lowest temperature examined, 1090°C - 1110°C, abundant amorphous material is present with equal amounts of mullite, cristobalite, quartz and protoenstatite. With increasing temperature, and development of the crystalline phases, the proportion of amorphous material decreases.

Fired samples are strong at all temperatures and water absorptions decrease with increasing temperature from 11.6% at 1090°C - 1110°C to 0.26% at 1250°C. During firing samples distorted, at temperatures of 1175 - 1200°C and above, in thin walled products (3 millimetre thick).

Elimination of 10% feldspar from body SCT4 with an increase in the talc and clay components resulted in an increase in fired water absorption (Sample SCT6) to 4.7% at 1240°C-1270°C. However, most of the absorption was due to surface porosity of the sample which recorded a permeability of less than 0.1 millidarcys. The fired mineralogy consisted predominantly of cordierite with accessory cristobalite and traces of mullite, protoenstatite and quartz.

Substitution of the Ball Clay 'H' in body SCT6 for Axedale ball clay in SCT8 resulted in an increase in the casting rate. The fired water absorption of the product remained similar.

By eliminating the alumina from body SCT8 and increasing the ball clay and china clay, resulting in a body of similar magnesium but higher silica and lower alumina content, a self glazing fully vitrified product was produced at 1260°C. X-ray diffraction showed that the product consisted of well crystalline cordierite with trace to accessory amounts of protoenstatite, cristobalite, quartz and mullite.

X-ray data and water abosrption results are given in Table 7.

6. DISCUSSION - SLIP CAST CORDIERITE BODIES

The preliminary work indicates that products consisting of a high proportion of cordierite may be produced from a number of talc, clay, alumina and feldspar mixtures which are readily slip cast in plaster moulds. Slips incorporating Gumeracha talc require high levels of deflocculant and generally exhibit a degree of instability, changes in viscosity and thixotrophic behaviour, over a period of days which may require attention to maintain uniform casting properties.

Results obtained indicate that porous (earthenware) and impervious (stoneware) products may be manufactured from talc containing bodies and that ovenware products may be manufactured which contain a significant proportion of cordierite.

Distortion observed on firing in thin walled castings of Body SCT4 may be eliminated by increasing the wall thickness and maintaining a temperature slightly below 1250°C to produce a vitrified product.

7. DEVELOPMENT OF EARTHENWARE TALC/CLAY SLIP FOR HOBBY CERAMICS

Over the past five years or so the hobby ceramic field has grown extensively within the eastern Australian States and more recently in South Australia. To a large extent this market has been supplied by imported materials including clay slips and glazes.

A project was thus initiated, at the request of the South Australian Department of Mines and Energy to develop a slip utilizing South Australian talc which would be suitable for this market and be compatible with the range of imported glazes used extensively by the hobby ceramists.

Slips currently produced and available in Australia were, in general, unsuitable for use with many of the imported glazes which had a tendency to craze on the local slips.

The imported glazes are generally applied by brushing on bisque fired castings (1100°C) followed by a glost firing usually at 1015°C-1040°C.

7.1 Objectives

The degree of control of slip characteristics exercised in a commercial production shop which may be required to manufacture thousands of identical pieces daily over a period of months or years is totally foreign to the operation of the hobby ceramist. For this reason the investigation was approached with a relatively broad range of objectives which are considered to be of primary concern to the specific intended market. The object of the investigation was to produce a slip which :

(a) Is readily manufactured from locally available components, including Gumeracha talc, which maintain a reasonable degree of consistency over a period of time.

(b) Has satisfactory casting properties and behaviour suited to the hobby ceramic field.

(c) When fired to 1100°C the resultant product to have adequate strength, durability and appearance to be regarded a satisfactory earthenware product.

(d) After bisque firing may be readily glazed with the imported range of glazes and after glost firing these glazes to provide a surface free of defects, in particular crazing.

7.2 Materials

In addition to some of the materials previously used during the investigation of talc bodies, a local plastic clay, a first grade white talc and a ground limestone were used during the course of the development work.

7.2.1 McLaren Vale White

A plastic siliceous off-white clay containing approximately equal proportion of kaolinite and muscovite and a trace of potash feldspar. The clay fires to a hard pale yellowish grey product at 1100°C with an absorption of approximately 9%. The material, supplied by Clay & Mineral Sales Pty Ltd, was ground to minus 200 mesh (75 micrometres) B.S. for incorporation in casting bodies.

7.2.2 Calcium Carbonate

A preground yellowish limestone of minus 75 micrometres fineness.

7.2.3 Talc Ti

First grade white talc marketed by Minerals Pty Ltd, milled to minus 53 micrometres (2% retained).

Chemical analyses of the local clay and first grade talc are given in Table 4.

7.3 Preparation of Slips

Nine alternative slips were prepared based upon the known behaviour of the individual slip components and progressive data obtained during the investigation. Compositions are given in Table 8.

Each slip was prepared by blunging the dry components in distilled water to which 0.6% of liquid sodium silicate had been added. Final adjustments to the degree of deflocculation of the slips, where required, was effected by additions of sodium hexametaphosphate (Calgon) during blunging. All slips were prepared at 65% solids content and allowed to stand for 30 minutes prior to testing.

7.4 Slip Properties - Behaviour & Results

7.4.1 Viscosity Determinations

After standing the slips were stirred prior to measuring their viscosity using a Brookfield Syncro Lectric Viscometer fitted with a No. 3 spindle at shear rates of 10, 20, 50 and 100 rpm to determine the relationships of shear stress to rate of shear.

Two of the slips proved unsatisfactory at this stage due to excessive viscosities and were eliminated from the testing programme. Results obtained from the remaining seven test slips are shown in Table 9 and Graphs 1 and 2.

7.4.2 Casting Behaviour

Slips were cast in plaster moulds for 25 minutes prior to draining for 15 minutes. All slips showed good casting and clean draining behaviour. Although slight variations in casting rate were noted measurements of wall buildup were not recorded since this property varies extensively depending upon a large number of parameters which differ from one cast shop to another.

When cast in a relatively dry mould (5-10% moisture) all slips released within 1 hour and casts were sufficiently rigid for stripping and trimming within 1½ hours of casting.

7.4.3 Drying & Firing

Green casts were air dried for 12 to 24 hours after stripping followed by severe drying at 105°C for 24 hours. Dry casts were strong, hard and readily handled without sustaining damage.

The casts were bisque fired in an electric kiln to 1100°C over a 7 hour period including a 1 hour soak on peak temperature. Drying and firing shrinkages, together with 24 hour cold water absorption and fired colour results are shown in Table 10.

7.4.4 Glazing

Four Duncan E-Z Flow ceramic glazes were applied to the fired products which were re-fired to 1040°C over a 6½ hour firing cycle including a one hour soak on peak temperature.

The glazes used were : Opaque White GL-638, Walnut Brown GL-666, Royal Blue GL-634 and Bottle Green GL-669. No glaze defects which are attributed to poor 'fit' of body and glaze were observed on the fired products.

7.4.5 Resistance to Crazing of Glazes

A glazed product manufactured from each of the seven test slips, was immersed in steam at a pressure of 690 kN/m^2 (100 psi) for 2 hours in accordance with the procedure recommended for determining the crazing resistance of glazed ceramic tiles (BS 1281:1974 Specification for Glazed ceramic tiles and tile fittings for internal walls).

Glazes on two of the experimental bodies (Nos 6 & 7) either crazed or developed fine hairline cracks as a result of the test. These bodies contained the highest percentage of potash feldspar, 10% and 15% respectively. The crazing observed in these glazes is a result of moisture expansion of the bodies which will occur gradually when the glazed ware is in service, although the time lapse will depend upon the imposed conditions. The steam pressure test accelerates the rate of crazing.

7.5 Discussion - Earthenware Talc/Clay Slips

Of the nine slips investigated five may be considered as suitable for Hobby ceramics. These slips, Nos 1, 3, 5, 8 and 9 may be readily manufactured from locally available materials, have good casting properties, fire satisfactorily and are compatible with the Duncan glazes.

Of these five, slip No. 1 has the highest casting viscosity and a higher yield point (see Graph 2) than the remaining slips and this could, under some circumstances, reduce its usefulness. Consideration must be given to the market proposed which is not acquainted with many factors such as slip temperature and salt content of make up water which will further increase the viscosity and yield point of the slip resulting in variation in the properties and behaviour of the slip. This body is therefore assigned a low priority.

On the basis of fired properties all of the remaining bodies have low total shrinkages of 5% to 6%. In particular the firing shrinkages of the experimental bodies are very low, approximately 1%. Water absorption of the fired products are acceptable for the intended market. All slips develop adequate strength for their intended market, exhibit a sharp sound ring, and do not show crazing due to moisture expansion.

The fired colour of the four potential slips may be used as a determining selective factor in which case bodies 5 and 9 are distinctly less pinkish than bodies 3 and 8, and may therefore be preferred. The pinkish discolouration of the latter bodies is attributed to the higher iron content of the T'2 talc compared with T1 talc.

8. CONCLUSIONS

The results of the investigation into areas for utilization of Gumeracha talc have shown the material to have a wide range of potential applications in ceramic bodies.

Of primary interest is the development of high proportions of well crystalline indialite, at relatively low temperatures, in bodies designed to approach the theoretical chemical requirements for cordierite formation.

Considering the simple two component bodies consisting of approximately 33% Gumeracha talc, containing 5% of natural albite, and 67% of high alumina Williamstown clay the data obtained from the investigation suggests that either low absorption or porous cordierite (indialite) products may be manufactured with properties largely readily controllable by varying the grinding criterion for the clay/silimanite component and the firing cycle. Medium grade refractories, suitable for use up to approximately 1300°C, with the required characteristics for normal duty refractory shapes such as kiln shelves, supports and blocks are considered within the scope of attainability with the talc/Williamstown body.

The area of vitrified cordierite bodies from the same mix by adjusting the fineness of the components and the firing cycles requires further investigation particularly in relationship to the firing range of the fine grained bodies. Cordierite bodies generally exhibit relatively short firing ranges which may cause problems in industrial production situations.

Slip cast bodies, again of high cordieritic composition, were successfully produced in the laboratory from blends incorporating Gumeracha talc, clay, alumina and feldspar. Results obtained suggest that both cookware and general thermal shock resistant products and utility ware of good quality are within the scope of the talc bodies investigated. However, although there is considerable merit in using a low expansive body for cookware there are disadvantages relating to the problems of glazing such products. This area requires extensive consideration.

As a general ceramic body component Gumerahca talc has been shown to be suitable for the manufacture of slip cast and glazed earthenware articles of comparable quality to those produced from imported slips as used extensively by hobby ceramists. Items produced in the laboratory during the earthenware investigation are shown in Figs 1 - 3.

The known large reserves of lower grade talc in close proximity to Adelaide and the broad range of ceramic suitability of the material, as indicated by the investigation undertaken, suggest that the deposits are a valuable source of raw material for the ceramic industry.

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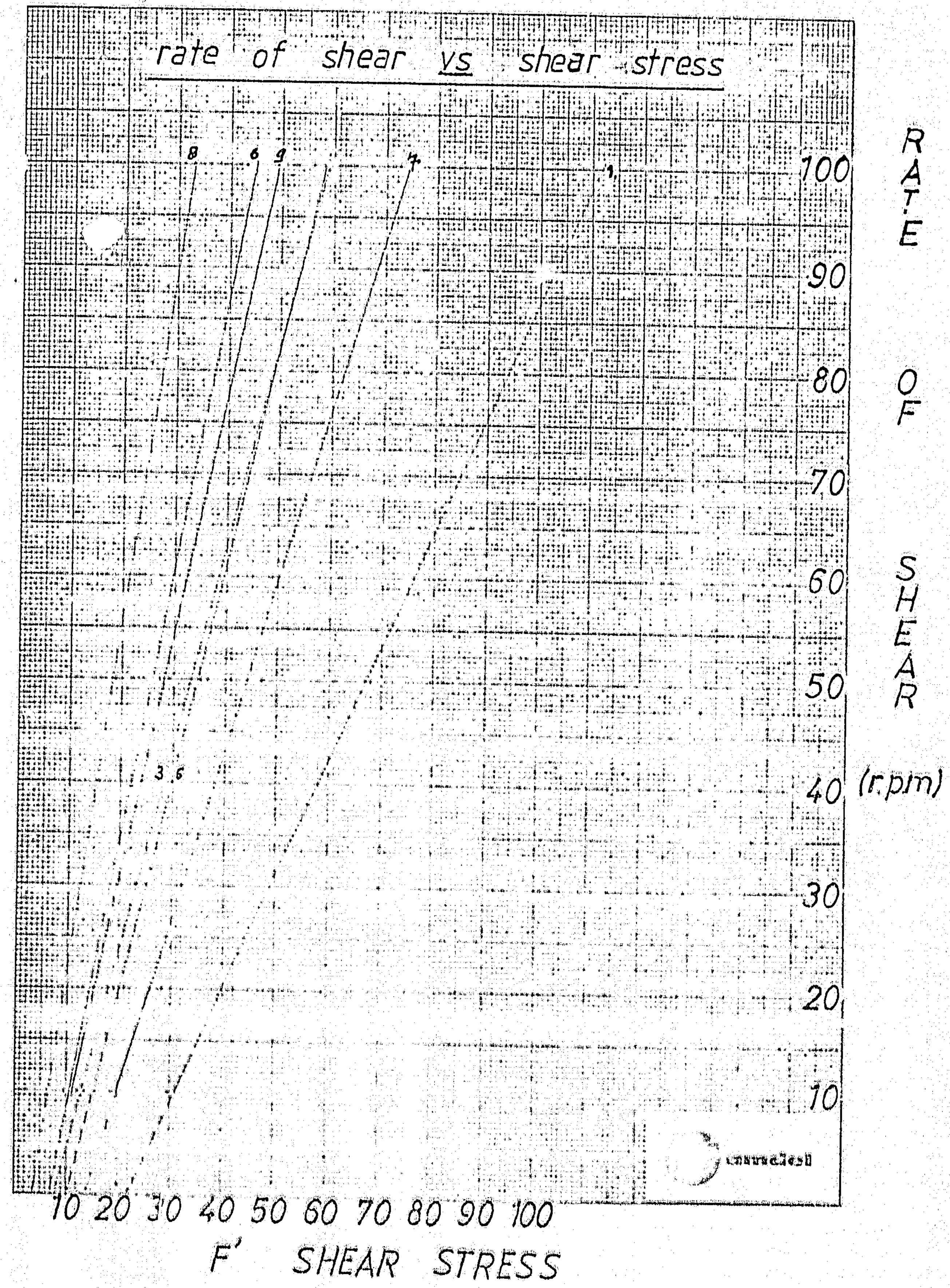
GRAPH 2


rate of shear vs shear stress
8
6
9
7
1
3
5
100
90
80
70
60
50
40
30
20
10
RATE OF SHEAR
(r.pm)
10 20 30 40 50 60 70 80 90 100
F' SHEAR STRESS

GRAPH 1

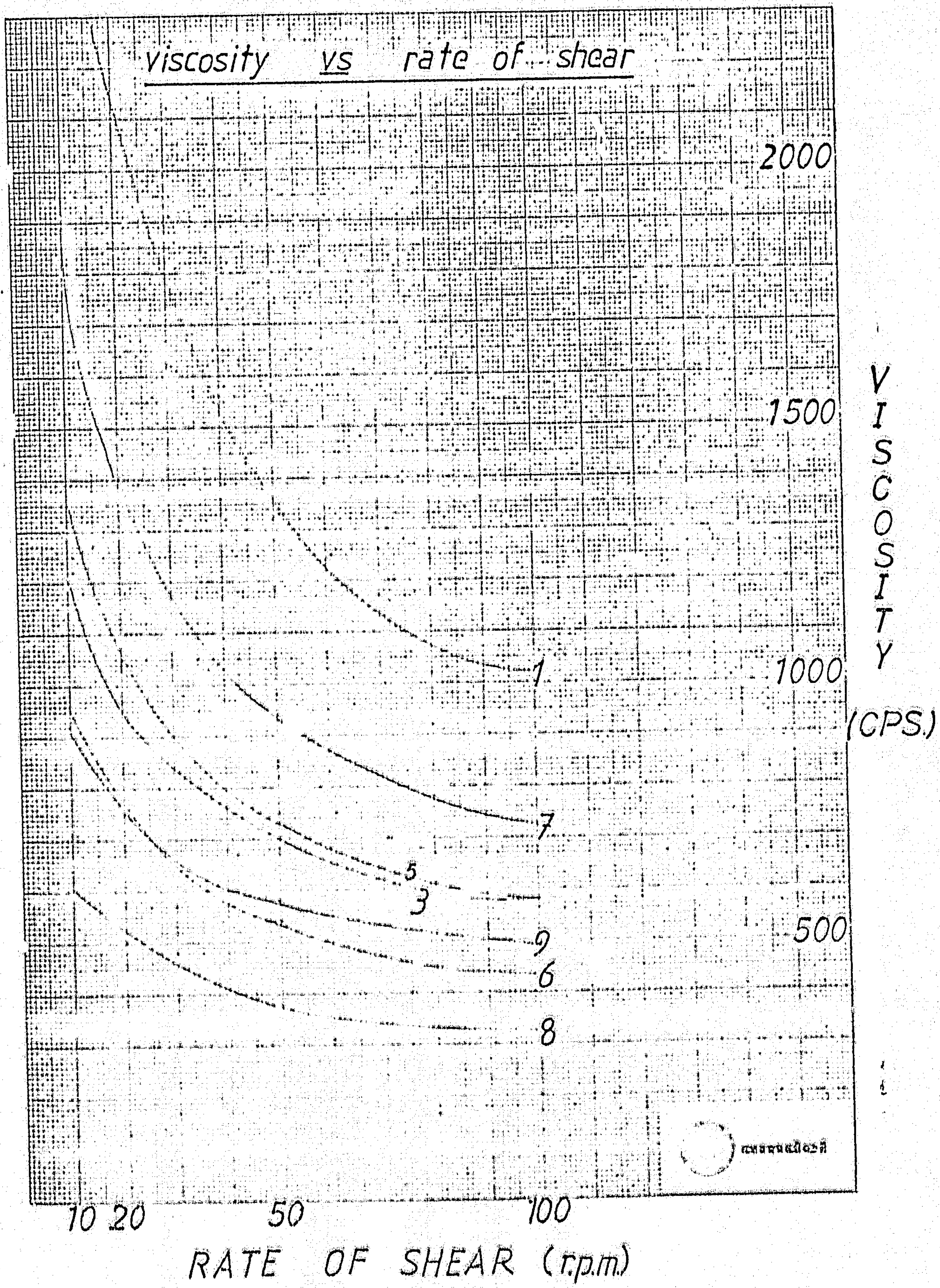

viscosity vs rate of shear
2000
1500
1000
500
VISCOSITY
(CPS.)
1
7
5
3
9
6
8
10
20
50
100
RATE OF SHEAR (r.p.m.)

Fig. 3 Cast earthenware articles produced from talc slips.

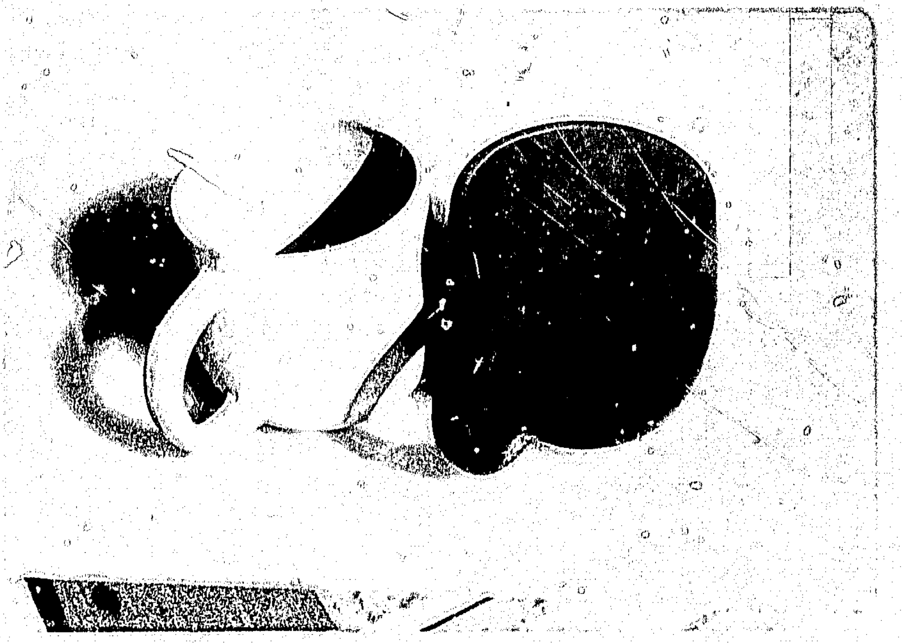


Fig. 1 Cast earthenware articles produced from talc slips.

Fig. 2 Cast earthenware articles produced from talc slips.

TABLE 9: VISCOSITY DETERMINATIONS (EARTHENWARE SLIPS)

Slip	Shear Stress/Viscosity (cps) 1	3	5	6	7	8	9
Rate of shear(s) rpm							
10	29.5/2950	12/1200	13.5/1350	9.5/950	18.5/1850	6.2/620	9.2/920
20	42/2100	19/950	21/1050	15/750	28/1400	10/500	15/750
50	68/1360	35/700	36.5/730	27/540	47/940	18.8/376	29/580
100	100+/1000+	58/580	58/580	43/430	72.5/725	33/330	49/490

TABLE 10: SHRINKAGE & ABSORPTION RESULTS - EARTHENWARE BODIES

Slip	Drying Shrinkage %	Firing Shrinkage %	Total Shrinkage %	Water Absorption %	Fired Colour
1	3.7	2.3	6.0	18.7	Pink
3	5.0	1.0	6.0	19.2	Pink
5	4.3	0.7	5.0	16.7	Green/white
6	5.0	1.0	6.0	16.1	Cream
7	6.3	0.5	6.8	10.6	Pink/cream
8	3.8	1.1	4.9	15.0	Pink/cream
9	5.3	0.7	6.0	15.8	Cream

TABLE 8: COMPOSITIONS OF EXPERIMENTAL EARTHERNWARE SLIPS

Slip No.	Composition %							Deflocculant
	Talc T'2	McLaren White	Talc T1	Ball Clay 'H'	Axedale Ball Clay	K Feldspar	Whiting	
1	35	50					15	0.6% sodium silicate 0.2% calgon
2	30	45				10	15	0.6% sodium silicate
3	35			50			15	0.6% sodium silicate
4	35				50		15	0.6% sodium silicate
5			35	50		5	10	0.6% sodium silicate
6			30	50		10	10	0.6% sodium silicate
7			35	50		15		0.6% sodium silicate
8	30			50		5	15	0.6% sodium silicate
9			35	50			15	0.6% sodium silicate

TABLE 7: MINERALOGY AND WATER ABSORPTION OF FIRED SLIP CAST CORDIERITE BODIES

Body No./Firing Temp.°C	SCT4 1090°C to 1110°C	SCT4 1175°C to 1200°C	SCT4 1225°C	SCT4 1250°C	SCT6 1240°C to 1270°C	SCT9 1260°C
<u>Mineralogy</u>						
Cordierite/Indialite	-	Tr	Tr	D	D	D
Mullite	A	A	A	A	Tr-A	Tr
Cristobalite	A	D	A	-	A	A-Tr
Protoenstatite	A	A	A	A	Tr	Tr-A
Quartz	A	Tr-A	Tr-A	Tr	Tr	Tr
Sapphirine	-	A	A	A	-	-
Amorphous Material	Abundant	Present	Present	Present	-	Very minor
Water Absorption %	11.6	4.6	0.26	0	4.7	Vitrified

<u>Key</u>

D = Dominant (probably greater than 30%)

A = Accessory (probably 5-15%)

Tr = Trace (probably <5%)

TABLE 6: SUMMARY OF SLIP PREPARATION AND CASTING PROPERTIES

Body No. SCT	1	2	3	4	5	6	7	8	9
Sodium silicate %	*	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sodium hexametaphosphate %	*	0.4	0.27	0.2	0.1	0.225	0.2	0.3	0.2
Viscosity (poise)	*	35	30	8	4.5	7.6	7	6	7.5
Casting Rate	*	Rapid	Good	Good	Good	Good	Good	Good	Good
Drain	*	Fair	Clean	Clean	Clean	Clean	Clean	Clean	Clean
Release	*	Poor	Poor	Satisfactory 1 hour	Nil	Satisfactory 35 mins.	Poor	Satisfactory	Satisfactory
Defects	*	Cracked in mould.	Some sticking in mould. Cast soft.	-	-	-	Some sticking in mould	-	-

* Could not obtain satisfactory deflocculation.

TABLE 5: SLIP CASTING BODIES, COMPOSITIONS AND CALCULATED CHEMICAL ANALYSES (FIRED BASIS)

Body No. & Composition	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5
SCT1 Talc 33% Birdwood Clay 67%	56.40	1.36	30.32	0.59	0.72	9.89	0.10	0.20	0.09	0.04
SCT2 Talc 40% Feldspar 10% Alumina 20% Bridwood Clay 30%	48.19	0.67	35.83	0.58	0.87	11.97	0.11	0.60	1.08	0.04
SCT3 Talc 40% Feldspar 10% Ball "H" 30% Alumina 20%	53.39	0.47	29.0	0.95	0.87	12.28	0.24	0.8	1.83	0.04
SCT4 Talc 30% Feldspar 10% "H" 24% Alumina 10% China 26%	56.43	0.49	28.99	0.98	0.65	9.31	0.27	0.85	1.80	0.03
SCT5 Talc 39.4% Feldspar 10.6% "H" 24% China 26%	62.87	0.51	19.74	1.04	0.85	12.11	0.29	0.92	1.86	0.04
SCT6 Talc 34.4% "H" 26.2% Alumina 10.9% China 28.5%	55.39	0.54	29.72	1.04	0.75	10.65	0.27	0.52	0.84	0.04
SCT7 Talc 35% Silica 10% Axedale 27% China 28%	65.04	0.64	20.06	0.82	0.76	10.77	0.15	0.48	1.08	0.04
SCT8 Talc 34.4% Alumina 10.9% Axedale 26.2% China 28.5%	54.38	0.62	30.96	0.82	0.75	10.59	0.16	0.46	1.23	0.04
SCT9 Talc 23.8% Axedale 23% China 35.2	60.72	0.76	24.54	0.93	0.71	10.18	0.18	0.52	1.28	0.04

TABLE 4: CHEMICAL ANALYSIS OF RAW MATERIALS USED IN SLIP CASTING BODIES

	Ball Clay "H"	China Clay K37L	K. Feldspar	Axedale Ball Clay C/1Q	McLaren White	Talc T1
SiO_2	65.6	45.4	67.0	61.02	69.4	63.6
TiO_2	1.2	0.4	–	1.50	2.2	0.03
Al_2O_3	20.5	38.0	18.0	24.6	23.64	0.38
Fe_2O_3	1.8	0.8	0.3	0.94	1.37	0.36
FeO	–	–	–	–	0.05	0.56
MnO	–	Tr	–	–	0.01	–
MgO	1.0	0.3	0.1	0.81	0.43	29.7
CaO	0.5	0.3	0.3	0.07	0.47	0.12
Na_2O	0.7	0.4	3.6	0.44	0.22	0.07
K_2O	2.4	0.4	10.3	3.13	1.55	0.04
P_2O_5	–	–	–	–	0.04	–
L.O.I.	6.2	13.6	0.4	7.63	–	5.27

TABLE 3: CORDIERITE BODIES - FIRING CONDITIONS AND FIRED PROPERTIES

Body	Nominal Size Analysis	Method of Preparation	Firing Conditions	Temperature °C	Fired Composition					Physical Properties				
					Indialite	Sillimanite	Protoenstatite	Quartz	Mullite	Firing Shrinkage %	Water Absorption %	Apparent % Porosity	Bulk Density	Modulus of Rupture MPa
Talc/ Williamstown 32.8% Talc 67.2% Clay	Minus 75 micrometres	Pressed 224 kg/cm²	Electric 3 hrs inc. 2 hr soak	1270	D (51)	A (9)	Tr	Tr	-	3.9	2.3			
				1290	D (52)	A (9)	-	Tr	-	3.4	0.31			
				1310						Distorted	0.3			
	Minus 300 micrometres	Pressed 224 kg/cm² MOR Bars pressed 100 kg/cm²	Gas 4 hrs inc. 1 hr. soak	1250	D (37)	A (13)	Tr-A	Tr	-	2.4	13.4	26.5	1.97	26.9
				1280	D (57)	A (11)	Tr-A	Tr	-	2.5	11.8	24.3	1.99	28
				1310	D (53)	A (10)	Tr	Tr	-	2.2	10.1	22.9	2.0	25
				1340	D (61)	A (9)	-	Tr	-	3.2	4.4	9.7	2.13	34
				1370	D (64)	A (7)	-	Tr	-	2.3	9.2	20.4	2.02	30.5
				1400						2.1	10.3	20.7	1.98	
	20.6% + 300µm 33.5% + 150µm 43.7% + 75µm 47.4% + 53µm	Pressed 224 kg/cm²	Electric 1½ hrs inc. 1 hr soak	1250	D (46)	A (13)	Tr	Tr	-	2.9	12.1	24.3	2.0	
				1280	D (49)	A (12)	Tr	Tr	-	2.5	11.7	23.5	2.0	
				1310	D (49)	A (13)	-	Tr	-	1.7	12.5	34.7	1.98	
				1340	D (58)	A (12)	-	Tr	-	1.6	13.8	26.5	1.92	
				1370	D (65)	A (10)	-	Tr	-	1.7	10.3	20.6	2.01	
			Electric Refired 1280°C Sample 7 hrs	1280	D (50)	A (10)	-	Tr	-	Refired Shrinkage -0.2	11.3			
			Refired 1310°C Sample	1280	D (46)	A (12)	-	Tr	-	Refired Shrinkage -0.2	12.0			
Talc/ Birdwood 32.8% Talc 67.2% Clay	Minus 75 micrometres	Extrusion 30% moisture Drying Shrinkage 4.9%	Gas 4 hrs inc. ½ hr soak	1250	D		Tr	-	Tr	3.7	20.4			
			4½ hrs inc. ½ hr soak	1350						Molten				

Note: The figures in brackets demonstrate the variation in amounts of the two major components but bear no relation to percentages. The figures were derived from a geometric average of four peak heights of the X-ray patterns.

Key:

D = Dominant (probably greater than 30%)
A = Accessory (probably 5-15%)
Tr = Trace (probably <5%)

TABLE 1: MINERALOGY AND CHEMICAL ANALYSIS OF RAW MATERIALS USED IN CORDIERITE REFRACTORY BODIES

	Gumeracha 3rd Grade Talc	Williamstown Clay		Birdwood Clay
Talc	D	Kaolinite	CD	
Feldspar (albite)	app. 5%	Sillimanite	CD	
Dolomite	Tr	Muscovite & Paragonite	SD	
Quartz ?	Slight Tr	Quartz	A	
		Pyrophyllite	Tr	
SiO_2	61.2	44.31		45.3
TiO_2	0.16	1.36		1.7
Al_2O_3	1.51	43.42		38.3
Fe_2O_3	0.83	0.50		0.4
FeO	2.07	-		-
MnO	0.01	<0.01		-
MgO	28.44	0.09		0.05
CaO	0.13	0.11		0.06
Na_2O	0.56	0.52		-
K_2O	0.06	1.0		0.01
P_2O_5	0.10	0.01		-
L.O.I.	4.70	7.66		13.8
	99.77	98.98		99.71
H_2O^+	4.46			
H_2O^-	0.24			

D	Dominant
CD	Co-dominant (approximately equal proportions)
SD	Sub-dominant (15-30%)
A	Accessory (5-15%)
Tr	Trace (less than 5%)

TABLE 2: DRY SCREEN ANALYSIS OF TALC SAMPLE T/2

Size µm	Screen Sizing B.S.S.	Cumulative % Retained
+150	100 mesh	0.02
-105	150 mesh	0.02
-75	200 mesh	0.26
-53	300 mesh	2.28