

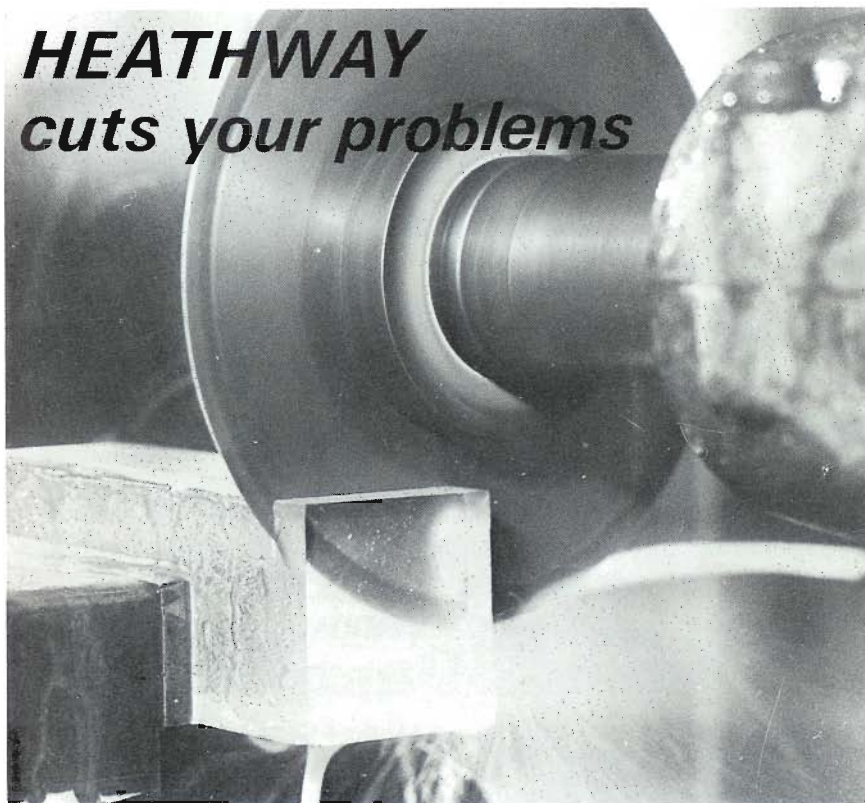
British Society of  
**Scientific  
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**Journal**

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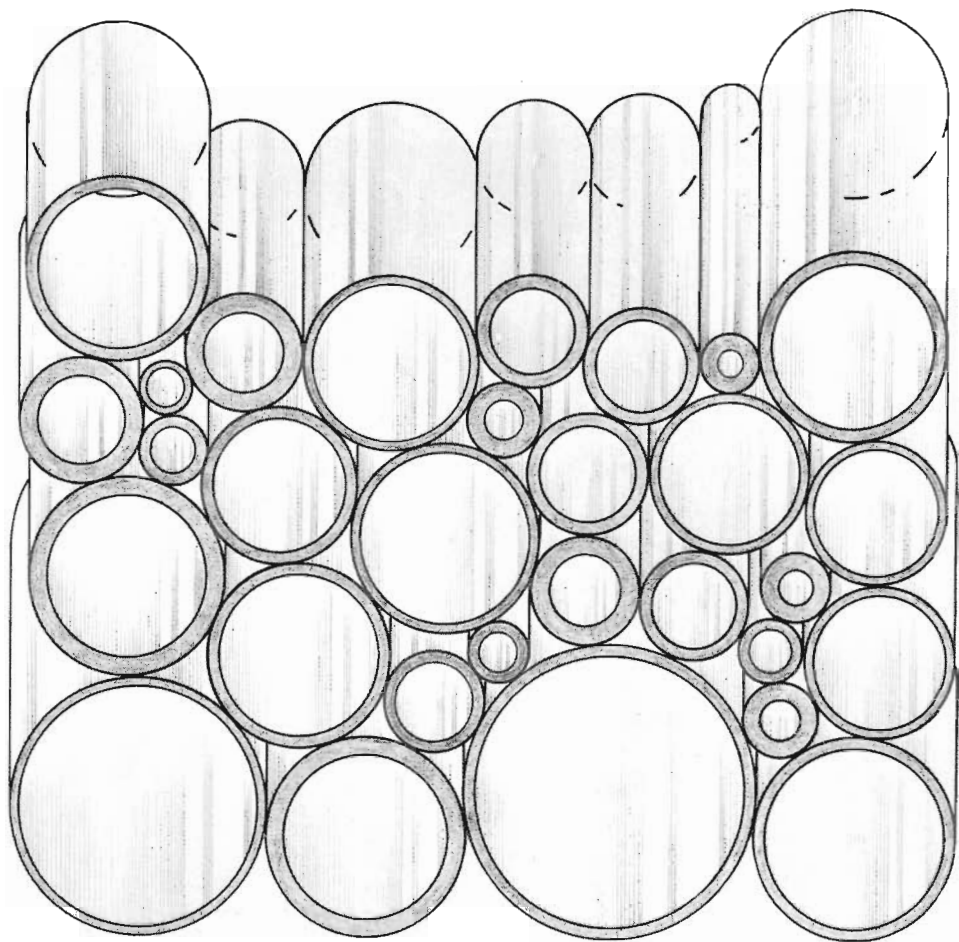
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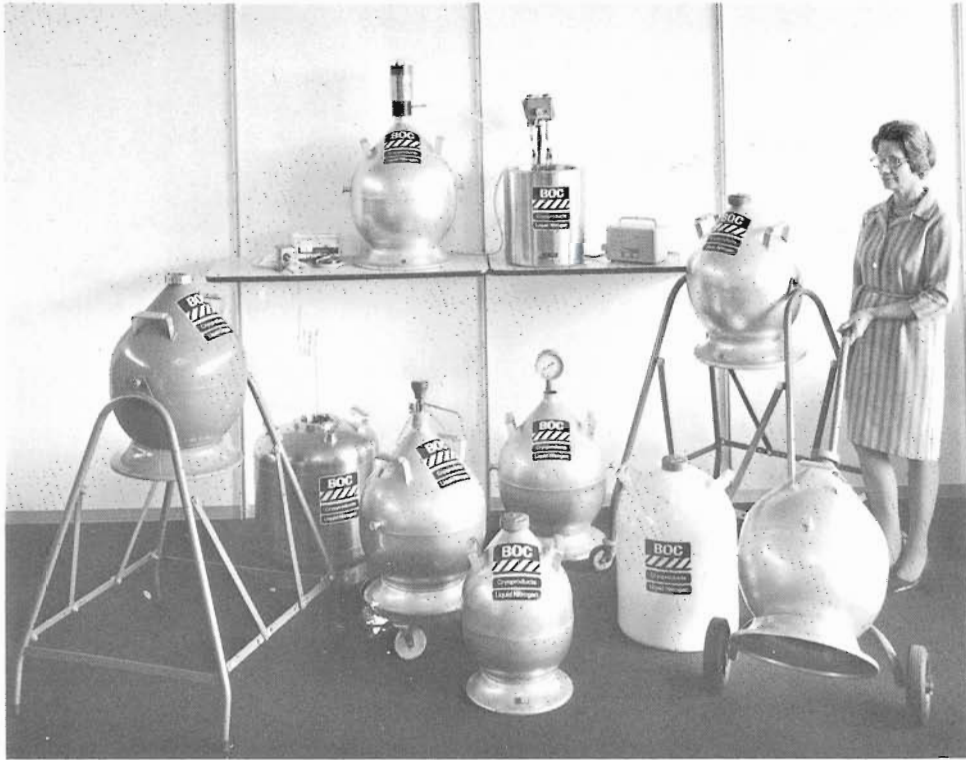
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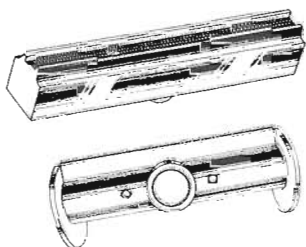
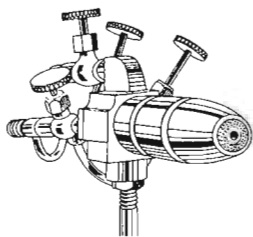
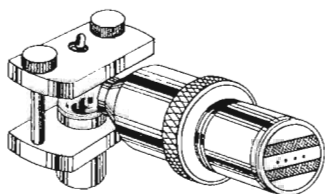
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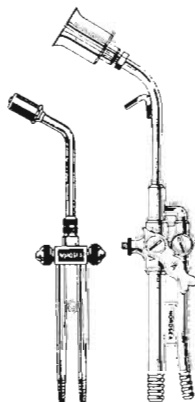
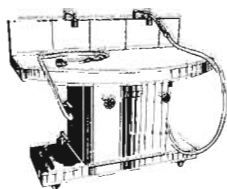


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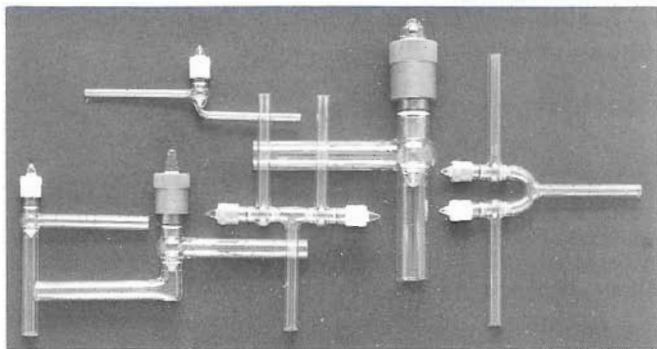


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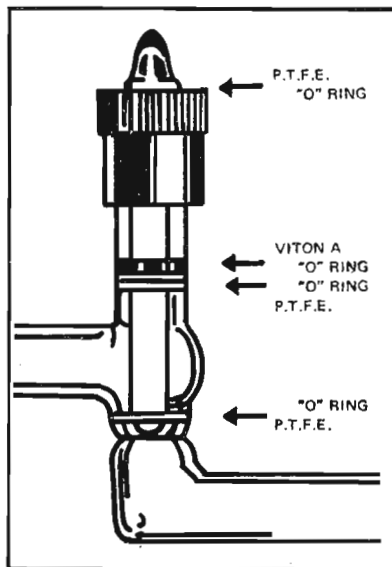
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# British Society of Scientific Glassblowers

Founded 1960

President: Mr. STAFFORD SCHOLES

VOL. 13, OCTOBER 1975, No. 4.

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## **MACHINABLE GLASS-CERAMIC: A NEW MATERIAL FOR VACUUM EQUIPMENT BY DENNIS MOG, CORNING GLASS WORKS**

Vacuum equipment users — particularly those involved in research — often need ceramic parts for use as insulators, electrical standoffs and mechanical supports. Ceramic houses sometimes can supply standard pieces as stock items, but frequently a custom part may be necessary or preferable. If particular items are not available off the shelf, then users have two alternatives: have the part custom made by a vacuum equipment supplier or ceramic supply house or build it themselves. Often neither alternative offers an attractive solution to the problem, primarily because of cost or because available materials do not lend themselves to easy fabrication.

A new material with a combination of properties for vacuum applications not offered by other materials such as alumina, boron nitride, lava, glass, thermoplastics or glass-bonded mica has recently been introduced by Corning Glass Works.

In addition to offering all properties required for vacuum operation, Corning's new machinable glass-ceramic (Corning Code 9658) can be machined to precise tolerances with conventional metalworking tools, thus solving a major parts-fabrication problem. The material does not sacrifice strength, hardness or porosity to achieve this machinability, nor does it have to be fired after machining. Figure 1 shows a 6-inch diameter piece of machinable glass-ceramic being grooved for "O" rings with a carbide tool on a standard lathe.

Original equipment manufacturers, as well as users of just a small quantity of parts, require a material with which they can economically achieve precision tolerances and a fine surface finish.

Existing materials for these applications all exhibit particular weaknesses. For example:



Fig. 1

Glass and fired alumina must be machined by diamond grinding, an expensive and time-consuming process. Lava and green alumina must be fired and shrinks and breaks during firing.

Boron nitride has been used extensively in vacuum work because it can be machined. However, it absorbs water and other contaminants and must be baked before use. It also is weak and tends to wear or break during use. It also is expensive.

Conventional machinable ceramics, such as alumino silicates, or glass-bonded mica tend to chip during machining. Other machinable ceramics obtain their machinability at the expense of strength and porosity.

Thermoplastics, including Teflon and Delrin, can be used only at relatively low temperatures and present a problem of cold flow.

### **What is Machinable Glass-Ceramic?**

Conventional glass-ceramic materials were introduced by Corning in 1957. Basically, they are materials that have been converted into crystalline ceramics from their original non-crystalline state through a process involving use of crystal-forming nucleating agents and heat treatment.

A glass batch containing a suitable nucleating agent is melted and formed into a transparent glass article by conventional glass-making techniques. The article is then cooled to temperatures causing precipitation of the nucleating agents.

Then the nucleated article is heated to a temperature at which growth of the nucleated crystals takes place. Original composition of the glass and the degree of heat treatment determine the type of crystallization and the material's final properties.

The new machinable glass-ceramic exhibits unique mechanical properties, particularly in light of the fact that it is a glass-ceramic. Its combination of machinability and strength results from an unusual microstructure that makes it difficult for cracks to propagate.

During machining, the material is pulverized only in the localized region of the cut. It is the unique microstructure that also provides the material with an insensitivity to surface damage and good thermal shock resistance.

### **Machinability**

The material can be machined using standard metalworking tools and equipment. High-speed tools can be used, but carbide tools will stay sharper longer. A fine, non-abrasive powder comes off during machining. A coolant (water soluble oil) is used to cool the tool and trap the powder. The machined material is ready for use immediately. Firing is not required.

It is difficult to characterize the machinability of a material in a single index. However, it may be useful to compare the ease of cutting the machinable glass-ceramic with other materials.

Machinable glass-ceramic cuts as easily as brass or aluminium with a hacksaw. It cuts 10 times more easily than Corning's Pyroceram brand glass-ceramic when cut with a diamond saw. A 0.7-inch sheet of machinable glass-ceramic has been cut at a rate of seven inches a minute.

All of the standard metalworking operations – milling, threading, etc. – can be performed on the material. Because of the glass-ceramic's high strength, it can be cut into very thin sections. Wafers with a five-mil thickness have been cut and 10-mil thick tubes have been turned from rod stock. Figure 2 shows some representative parts machined from the material.

Precision tolerances can be achieved with the machinable glass-ceramic because of its very fine grain size. Parts have been machined with carbide tooling to tolerances of  $\pm 0.0005$  inch.

The material can be polished to less than  $\frac{1}{2}$  micro-inch AA using cerium oxide on pitch. The surface finish on an as-sawn part has been as good as 4 microinches AA. The material can be threaded and it has been drilled and tapped for 2-56 screw threads.

This ease of machinability means that users can take the glass-ceramic rod or sheet stock and fabricate it in their laboratory or shop into whatever special components they require. This lowers cost and substantially reduces the time between parts design and actual use. And users can also maintain better control over component design.

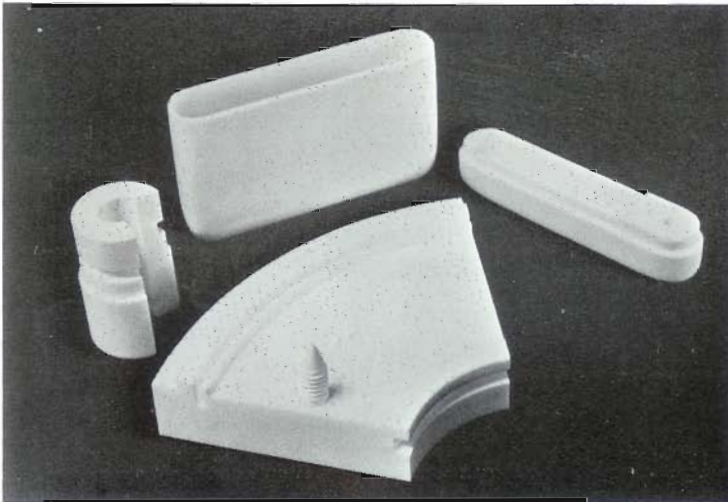


Fig. 2

At the same time, users have reported that parts they made were sufficiently strong because the material does not sacrifice strength or hardness to provide machinability. Corning quotes tensile strength of the machinable glass-ceramic at 15,000 psi and compressive strength at 50,000 psi.

## Other MGC Properties

Vacuum applications also call specifically for other properties inherent in the machinable glass-ceramic. In fact, the machinable glass-ceramic is the only available material that seems to satisfy all requirements of vacuum equipment users for custom ceramic parts.

It exhibits zero porosity and is vacuum tight.

It will not absorb water, and there has been no user evidence to date that the material out-gasses at elevated temperatures. In fact, users were initially apprehensive about the material's outgassing characteristics, but since have reported good results up to  $10^{-8}$  Torr. Other data is being collected.

The machinable glass-ceramic has a low helium permeation rate of

$$4 \times 10^{-12} \frac{\text{cm}^3 (\text{stp}) \cdot \text{mm}}{\text{sec} \cdot \text{cm}^2 \cdot \text{cmHg}} \text{ at } 140^\circ\text{C}.$$

It is a good electrical insulator with high dielectric strength (1000 v/mil) and high bulk resistivity ( $10^{14}$  ohm-cm at room temperature).

Its thermal properties are consistent with vacuum equipment requirements. Maximum use temperature is  $1000^\circ\text{C}$ . In addition, it has moderate thermal conductivity ( $0.004 \text{ cal cm/sec cm}^2 \text{ }^\circ\text{C}$  at  $25^\circ\text{C}$ ) and a high thermal expansion coefficient ( $94 \times 10^{-7}/^\circ\text{C}$  from room temperature to  $400^\circ\text{C}$ ;  $110 \times 10^{-7}/^\circ\text{C}$  from room temperature to  $600^\circ\text{C}$ ; and  $123 \times 10^{-7}/^\circ\text{C}$  from room temperature to  $800^\circ\text{C}$ ). The latter figure matches that of soda-lime glass. Table 1 lists various properties of Corning's machinable glass-ceramic.

## Sealing

A major requirement for a vacuum compatible insulator is that it be easily and hermetically sealable to glass, metal and ceramic. Because of the machinable glass-ceramic's expansion match to soda lime glass and some metals, it is capable of forming very good seals directly to these materials.

Ceramics are typically sealed using a complicated process of metallization followed by brazing. The Corning material can be sealed more simply using a glass frit process. In the glass frit process, powdered glass is placed between the machinable glass and the part to which it is to be sealed. The glass powder will melt during a firing process and flow to make a hermetic seal. In some cases, the glass frit devitrifies (crystallizes) after the seal is made which gives the seal a higher temperature capability than would be expected from the softening point of the original glass powder.

Seals can be made this way that are useful up to  $700^\circ\text{C}$  or higher. Figure 3 shows a feed-through made using Corning Code 7575 solder glass frit. The part was fired at  $450^\circ\text{C}$  and is useful at temperatures of  $425^\circ\text{C}$ .

**Physical Properties Table 1**

Property	Test Conditions	Description of Test	Nominal Value	Units
<b>General</b>				
Density	Corrected to 4°C	10 g sample archimedes method	2.52 157	g/cm <sup>3</sup> lb/ft <sup>3</sup>
Porosity	25°C	Hg intrusion	0	
Water Absorption		ASTM C-373, boiled in water and dried weight gain.	0	
Helium Permeation Rate	143°C		4.2 X 10 <sup>-12</sup>	cc stp—mm sec cm <sup>2</sup> —cm Hg
<b>Electrical</b>				
Volume Resistivity	500°C d.c.	ASTM C-657	10 <sup>7</sup>	ohm-cm
Loss Tangent	25°C, 10 kHz	ASTM D-150	0.003	
Dielectric Constant	25°C, 10 kHz	ASTM D-150	5.92	
Dielectric Strength	25°C sample thickness—	ASTM D-149, 1 kV/sec. oil: Dow Corning-200	1000	volt/mil
	25°C sample thickness— 10 mils, d.c.	ASTM D-149	3000	volt/mil
<b>Thermal</b>				
Thermal Expansion	RT to 400°C		94 X 10 <sup>-7</sup>	-°C
	RT to 600°C		110 X 10 <sup>-7</sup>	-°C
	RT to 800°C		123 X 10 <sup>-7</sup>	-°C
Thermal Conductivity	25°C	In-House Test Comparator	0.004	cal cm sec cm <sup>2</sup> °C
	77°F		11.68	BTU in hr. sq. ft °F
Maximum Use Temp.	Unstressed	Max. Temp. w/o change in crystal structure	1000 1800	°C °F
<b>Mechanical</b>				
Modulus of Rupture	25°C	ASTM C-158 modified for high temp.	15,000	psi
Compressive Strength	25°C, 10,000 lb.min.		50,000	psi
Modulus of Elasticity	25°C	Sonic Resonance Apparatus	9.3 X 10 <sup>6</sup>	psi
Shear Modulus	25°C	ASTM C-623	3.7 X 10 <sup>6</sup>	psi
Poisson's Ratio	25°C		0.26	
Knoop Hardness	25°C, 100 g	ASTM C-730	250	
<b>Chemical Durability</b>				
Resistance to Acid	5% HCl for 24 hrs. @ 95°C		87	mg/cm <sup>2</sup> wt loss
Resistance to Acid	5% HF for 24 hrs. @ 95°C		15	mg/cm <sup>2</sup> wt loss
Resistance to Base	N/50 Na <sub>2</sub> CO <sub>3</sub> for 6 hrs. @ 85°C		0.12	mg/cm <sup>2</sup> wt loss
Resistance to Base	5% NaOH for 6 hrs. @ 95°C		8.5	mg/cm <sup>2</sup> wt loss

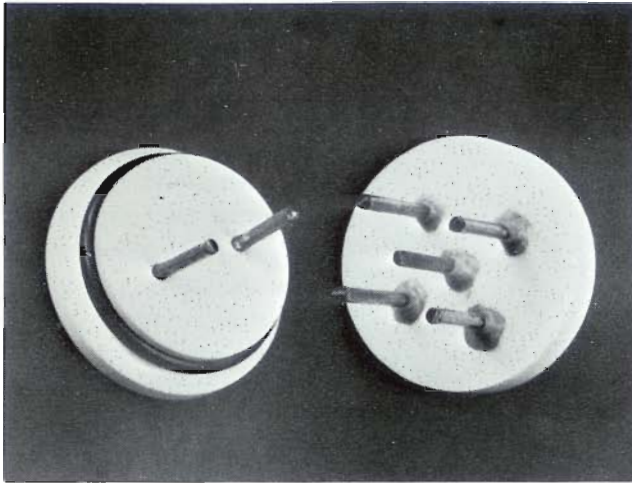


Fig. 3

### **Metalizing**

The machinable glass-ceramic also can be metalized as another approach to sealing. In one recent test in Corning laboratories a highly conductive silver coating was fully bonded to a polished surface of the machinable glass-ceramic. The sample withstood severe thermal shocks, and metal could easily be soldered to it. Figure 4 shows a piece of machinable glass-ceramic metalized with a conductive silver paste.

### **Applications**

The discussion to this point has primarily dealt with the use of a machinable glass-ceramic by vacuum equipment users who require custom-fabricated standoffs, jigs, fixtures, insulators and similar parts. These are for vacuum systems that operate in the range of  $10^{-6}$  to  $10^{-10}$  Torr. Ceramic parts are usually selected for their electrical insulating properties.

### **Sputtering**

A specific application for machinable glass-ceramic insulators is in sputtering, the process for depositing metal coatings on a substrate material by bombarding a source target with high energy, ionized particles in a vacuum environment. Sputtering is used in the production of integrated circuits by thin-film techniques and other production and research processes.

In order to electrically insulate various components of sputtering systems, vacuum-compatible materials with high dielectric characteristics are required. These materials must not outgas at the pressures and temperatures encountered. This means they must be capable of taking a good surface finish, be non-porous and hermetic, must not absorb water vapor, and must be able to withstand a bakeout of 150-400°C. The materials used most often for these parts have been alumina (94-99%), Teflon and, borosilicate glass and 96 percent silica glass.

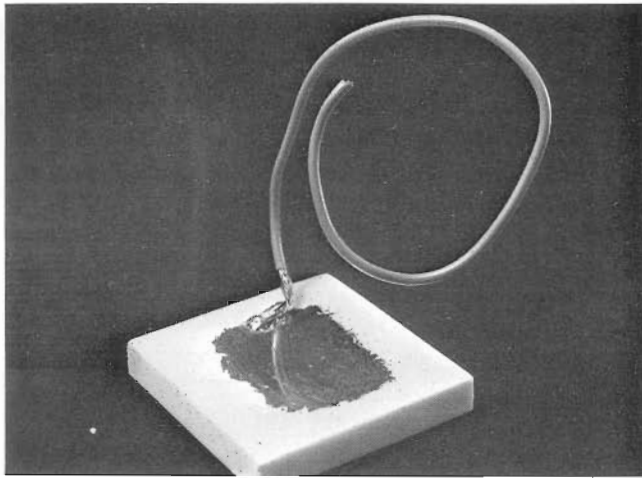


Fig. 4

Again, each of these materials presents certain disadvantages for sputtering applications. Alumina is not easily machinable and not readily available; Teflon has a low operating temperature and cold flows; glass will chip and break and is not machinable.

The machinable glass-ceramic appears to meet even the most rigorous requirements for sputtering, and samples have been supplied to manufacturers to confirm this.

#### **Vacuum Feedthroughs**

Two other vacuum applications for the machinable glass-ceramic are envisioned, although both depend upon user acceptance of the glass frit sealing method.

One application area is in manufacture of vacuum feedthroughs in high vacuum environments. These feedthroughs are designed to allow electrical connections to power sources and instruments outside the vacuum chamber. Feedthroughs must be hermetically sealed to vacuum walls or base-plates by welding or bolting.

High vacuum feedthroughs must be hermetic and non-outgassing up to  $10^{-11}$  Torr. They must be able to withstand vacuum bakeouts of  $450^{\circ}\text{C}$ . Most commercially available feedthroughs contain a ceramic insulator to isolate the electrically conducting components from the feedthrough flange and the wall of the vacuum system. The feedthrough may be disc-shaped or tube-shaped.

Alumina is now used as the insulating material and dielectric spacer in most high vacuum systems. But this material requires complicated and lengthy processing prior to use.

The glass frit sealing approach allows a very simple feedthrough manufacturing process. The feedthroughs shown in Figure 3 were made by drilling holes in the MGC, placing wires with the appropriate expansion coefficient through the holes, and sealing the leads with glass frit. Sylvania 4 and Dumet alloy have been used with the machinable glass-ceramic and Corning Code 7575 solder glass frit.

## Microwave Tube Parts

The other application area for the machinable glass-ceramic is in microwave tube parts. Klystrons, magnetrons and other microwave tubes contain insulating components that must be compatible with high vacuum internal environments. These components include headers, spacers, and microwave windows. They must be good electrical insulators and heat resistant. Headers and windows must make strong, hermetic seals with metal or ceramic tube envelopes. Headers for vacuum tubes are very similar in function and technical requirements to feedthroughs used in high vacuum systems.

Brazed alumina or glass sealed to Kovar are materials currently used for such parts. As with vacuum system feedthroughs, the machinable glass-ceramic has a high-use potential because of the simplicity of the glass frit sealing approach. Table II provides a comparison of properties of various materials used in vacuum applications.

Comparison of Materials Used in Vacuum Table 2

	Machinable Glass- Ceramic	Boron Nitride	Alumina	Glass Bonded Mica	Teflon	Fired Machinable Ceramics (Lava)	Unfired Machinable Ceramics Alumino-Silicates Magnesium-Silicates
Machinability	E	E	P	F	E	*	F
Strength	E	P	E	F	F	P	P
Outgassing Characteristics	E	P	E	F	F	P	P
Water Absorption	E	P	E	—	—	P	P
Vacuum Tightness	E	F	E	F	F	F	P
Operating Temperature	E	E	E	F	P	E	E
Dielectric Strength	E	E	F	F	E	P	F
Loss Tangent	F	E	E	F	—	P	F
Availability	E	E	F	F	E	E	E
Price	F	P	F	E	F	E	E
Large Sizes	E	E	F	P	—	F	E

E = Excellent

F = Fair

P = Poor

\* = Must be fired after machining

## User Experience

Because the machinable glass-ceramic is a relatively new material for vacuum applications, user experience with it is somewhat limited. However, preliminary reports by various research labs emphasise a number of the material's attributes.

For example, W.J. Scouler of MIT's Lincoln Laboratories has used the machinable glass-ceramic as a UHV insulator for electrical connections.

Citing adequate strength and temperature capability for the material, he said MGC was particularly useful for making special-configuration parts (connectors, washers, etc.). Corning's material replaced boron nitride in this application.

"It saves time over getting special-order ceramic parts," he said. "We plan to continue using the material as an electrical insulator in our vacuum systems."

He reported no problems with outgassing, although outgassing was a problem with boron nitride.

At Cornell University, Gert Broden reported use of MGC as a support and electrical insulator for a sample holder. The machinable glass-ceramic replaced lava in this application.

Broden said MGC can be machined to the right size, while lava has to be baked after machining and shrinks in the process. Also, he said lava might outgas if it has not been thoroughly baked, while MGC outgassing properties were said to be "excellent" both before and after bakeout.

He also rates both strength and temperature capability as good for his application.

Convenient machining and good surface finish were also special benefits for Thomas M. Hall of Cornell University who uses MGC to make insulators in field-ion microscopes and ion accelerators. He previously used alumina.

The non-porosity of MGC compared to boron nitride was a benefit cited by Carl Christianson of Brookhaven National Laboratory, Long Island, N.Y., who uses the material as insulating parts in high vacuum and high radiation environments.

Dr. Louis Biagi of the Lawrence Berkeley Laboratory of the University of California uses MGC as an insulator for a target plasma device. He previously used G-10 epoxy for low-temperature applications and alumina or boron nitride for high temperature applications.

He said MGC was selected for use because alumina could not be machined and boron nitride, which was weak, chalky and expensive, had poor outgassing characteristics. He said he has found no outgassing with MGC up to 1000°C.

Biagi said the material is readily machined into a substantial structure.

Because of its non-porosity, the machinable glass-ceramic also has been used at the University of California in a mass spectrometer as an insulator against contamination in high molecular organic materials.

In the same application boron nitride parts became contaminated in less than six months. The MGC now has been in use nine months, and there is no evidence of contamination.

## **Conclusion**

Inherent properties of MGC, coupled with user experience, provides substantial evidence that this glass-ceramic does fill a materials need for vacuum equipment.

Initial applications are in custom fabrication of various components for vacuum equipment and in parts for sputtering equipment. Pending acceptance of the glass frit sealing techniques for MGC, it also is apparent that the material will be useful for microwave tube parts and for vacuum feedthroughs.

**EXAMINATION RESULTS                      1975**  
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Khalid Hasim,

Evans Simpasa,

## MONKWEARMOUTH COLLEGE OF FURTHER EDUCATION:

**B.S.S.G. Elementary Examination 12th June 1975**

K. Rigg	Pass	D. Binks	Credit
B. Conway	Credit	P.J. Burton	Credit
D. Lamb	Pass	R. Blakey	Credit
R. Edmonds	Credit	J. Russell	Credit
D. Jobling	Distinction	J. Bloxham	Credit

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### Warley College of Technology:

**Date: 4th June 1975**

J.B. Jones	Pass
B. Lowe	Pass

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### St. Helens College of Technology:

**Date: 6th May 1975**

Colin Cash	Pass
Dave Bain	Pass
(Susan Ashley	Fail)

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## STAN FUSSEY

It is with deep regret that the society has learned of the death of Stan Fussey.

Stan's association with glass began with neon signs, then with G.E.C. at Hammersmith where he became a foreman. In 1947 he joined the Civil Service at Fort Halstead, from whence he transferred in 1955 to the Atomic Weapons Research Establishment at Aldermaston, where he rapidly expanded a small workshop into a highly sophisticated techniques laboratory, he becoming an expert in the manufacture and processing of glass to metal vacuum tube devices.

Stan was a founder member of the Society and in 1967 was chairman of a committee which put on the first two-day symposium, held at Reading. Stan founded the library in 1966 and edited the abstracts service which was part of the society journal, he was very active on behalf of the Thames Valley section and the society, bringing tremendous drive and enthusiasm to anything which he undertook.

His knowledge, experience and friendship will be sadly missed by all those who knew him.

## B.S.S.G. Annual Competitions 1975 — Results

### A.D. Wood Cup:—

Winner: Dean Jobling  
experience 10 months

James A. Jobling & Co.Ltd.,  
Sunderland

Other entries on show at Symposium from:—

Carol Patricia Smith of Messrs. May and Baker Ltd.,  
and James Russell of Messrs. James A. Jobling & Co.Ltd.

### Jobling Cup:—

Winner: Michael Holmes  
experience 5 years

University of Leeds,  
School of Chemistry.

### Thermal Trophy:—

Winner: S.R. Short  
experience 5 years

Messrs. Thermal Syndicate Ltd.,  
Wallsend.

Other entry on show at Symposium from:—

John Burns  
2 years experience

Messrs. Thermal Syndicate Ltd.,  
Wallsend.

### David Flack Memorial Trophy:—

Winner: Andrew Thompson  
with Collier and Pony

Messrs. James A. Jobling  
& Co. Ltd.

Certificates of Merit to the following:—

Raymond Adnitt for a Chess Set and Board.

W. Young for a Chess Set in fused silica.

S.G. Hill for a model Coach.

Frank Daysh for Madonna and Child — modern.

## PREVIOUS SUCCESSES OF 1975 ENTRANTS

Michael Holmes: Winner of Jobling Cup for 1975 has won:—

Jobling Cup 1974

A.D. Wood Cup 1973

A.D. Wood Cup 1972

Certificate of Merit in 1971 A.D. Wood competition.

W. Young:

Certificate of Merit in 1975 David Flack Memorial Competition.

Certificate of Merit in 1973 David Flack Memorial Competition.

Certificate of Merit in 1972 David Flack Memorial Competition.

Andrew Thompson: Winner of David Flack Memorial Trophy 1975 has won:—

David Flack Memorial Trophy 1974

Jobling Cup 1969

# THE DECORATION OF GLASS BY CERAMIC ENAMELLING

W.R. Povey

As the title implies enamelling of glass is carried out mainly to enhance the appearance of the glass article. To give colour or texture to the whole or part of an otherwise self-coloured homogeneous mass of glass, or to identify a product such as Coca-Cola, Pepsi-Cola contained in the glass bottle.

Unlike glazes applied to ceramic bodies to overcome porosity, or vitreous enamels applied to iron or steel to inhibit rusting, glass enamels never improve upon the desirable chemical and physical characteristics which glass already possesses. We are enamelling a near perfect substrate from all functional points of view. We are gilding the lily and must do so without wilting the flower.

All the efforts of the colour supplier and glass decorator are therefore aimed at improving the appearance of the glass and giving it visual appeal without affecting the functional performance of the article.

## GLASS ENAMEL COMPOSITIONS

The question arises, what is a glass enamel? The answer often given, that it is a soft lead glass fusing at a low temperature, is one which is only partially true. In the manufacture of a glass the constituents are generally melted together at a high temperature, whereas this technique is employed only for a small group of enamels embracing mainly transparent colours.

The majority of glass enamels comprise two main constituents, a flux or glass melting at a low temperature and a colour base or inorganic pigment. The constituents of the flux are melted together, and the resulting glass is ground to a fine powder with the pigment to produce the enamel. In some cases the flux and pigment mixture are sintered together, and subsequently reground, to complete a reaction between the two which might otherwise take place during the firing of the enamel decoration, with unfortunate results to the colour and gloss.

The flux, or fusible constituent, can vary widely in composition from a simple lead borate, or a lead silicate, to a highly complex borosilicate. This can contain, in addition to the oxides of lead, boron and silicon, its major constituents; alkalis, fluorides, alumina, lime, zinc oxide, zirconia, and titania to impart fusibility, gloss, corrosion and abrasion-resistance, and to modify thermal expansion characteristics. The composition of the flux also has an effect on the brilliance of the colour of the enamel, for it is possible to spoil the colour of a good pigment by combining it with an unsuitable flux.

The colour pigment is usually produced by calcining oxides at a high temperature, often between 1300<sup>o</sup> and 1400<sup>o</sup>, so as to produce, either alone or with other oxides, temperature-stable colours, or compounds which can impart a colour to glass. For example, the well-known cobalt aluminate pigment is used in 'cobalt' blue enamels; cobalt silicate in 'royal' blues; chromium oxide, in combination with other oxides, in greens; heat-modified iron oxides with alumina in browns; and mixtures of the oxides of cobalt, chromium, iron and manganese in blacks. In addition to oxides; certain other metallic compounds are used as pigments. Cadmium sulphide and cadmium sulpho-selenide are used in yellows and reds respectively; and "Purple of Cassius", containing gold and tin oxide, is used to produce a variety of colours ranging from pale mauves and pinks to deep purple and ruby red. White enamels are made by mixing with the flux a white pigment of high refractive index which is insoluble, or only sparingly soluble, in the enamel at its maturing temperature. Titanium oxide is now almost invariably used for this purpose.

There are two important differences in the use of enamels and coloured glasses: (1) enamels are used in layers seldom exceeding two to three thousandths of an inch, and often much thinner, whereas glass is usually many times this thickness, and (2) enamels must be re-melted on the surface of glassware at a temperature below that at which the glass will soften and distort. An enamel must therefore contain very much more colouring material than a glass, and to accommodate this refractory material, the flux constituent must fuse at a temperature well below that employed for firing the enamel on to glassware. This introduces us to the main problems which confront the ceramic colour chemist; the formulation and production of strongly coloured, brilliant enamels of suitable thermal expansion, high gloss and good chemical durability, maturing at as low a temperature as possible.

In the remaining part of this section the main properties required in enamels will be discussed.

## 1. COLOUR

The primary purpose of an enamel is to impart colour (including black and white) to the surface of glass. In the past the main concern of the colour-maker was the brilliance of colour and gloss, and the important properties of chemical durability and thermal expansion were somewhat neglected. This situation was brought about mainly by the designer, who frequently selected a colour scheme from patterns printed in organic dyes and pigments.

Some of the brilliant colours of organic dyes are very difficult to match with inorganic pigments, and can be matched if at all only at the expense of enamel durability. Eventually, failure of many of these enamels by corrosion led to a demand for improved durability, and discouraged the demand for tints obtainable only at the expense of other properties now considered essential.

Colour remains, however, an important enamel property, and considerable attention has been given to improving the inorganic pigments used in glass enamels, and to studying the effect on them of the various flux constituents.

Although most of the pigments are made by firing the constituents together at a high temperature, and nearly all the pigments when heated alone are stable up to  $650^{\circ}$ , the highest temperature used for firing glass enamels; partial decomposition or partial solution of the pigments in the flux often takes place when they are fused in contact with each other. Perhaps the best example of colour changes with varying firing temperature is found in the pink enamels, which rely on gold as the main colouring agent. These are brown at low temperatures, becoming pink at the optimum firing temperature, gradually changing to mauve and finally turning to pale blue when severely over-fired. These colour changes are due to changes in the physical nature of the colloidal gold, and the phenomena can be used as an indicator of the effective heat in the furnace in a similar way to Seger Cones or Holdcroft Bars.

These are extreme examples of colour changes, and it must not be imagined that all enamels vary in colour at different firing temperatures. By the selection of suitable fluxes, and the addition to the enamels of substances which inhibit these changes, colours have been largely stabilised, but to avoid trouble the enameller is advised to adhere as closely as possible to the specified optimum firing temperatures. When a firing range is quoted there should be little colour variation in this range.

## 2. FUSIBILITY

Enamels are formulated to fuse, or mature, between  $480^{\circ}$  and  $650^{\circ}$ . The choice of the enamel and the firing temperature will depend on the type of glass, the size and shape of the ware, and on its subsequent use. To achieve good results, enamels should be chosen which will mature with a good gloss just below the temperature at which the glassware will soften sufficiently to cause distortion. The main reason for decorating glassware at as high a temperature as it can withstand is that enamels maturing at a higher temperature can be used. These are usually more durable than the lower-maturing varieties.

## 3. DURABILITY

Durability is a very important property which has received much attention from the ceramic colour chemist in the last few years.

The principal reason why glass enamels are used for any work in preference to paint, cellulose and synthetic resin varnishes, is that they are much more durable. They have superior adhesion, hardness and resistance to corrosion by water, the atmosphere, acids, alkalis, sulphides and organic solvents. The degree and type of durability required in an enamel will depend on the type of glassware and its subsequent use. Thus, a fired-on label for an acid bottle for use in a laboratory must have a much higher order of durability than that demanded for decoration of drinking goblets. The marked improvement in durability of modern enamels has been accompanied by improved methods of assessing durability, although it must be admitted that accelerated tests cannot be relied upon implicitly to forecast the behaviour of the enamel in use, chiefly because of the variable conditions to which the enamel may be exposed.

### (a) Corrosion Resistance

If a piece of glassware decorated with low-fusing enamels of even the least-durable type could be preserved in dry air uncontaminated with fumes, the decoration would probably endure indefinitely. The introduction of moisture and fumes into the air, combined with fluctuations in temperature and the possible effects of sunlight, cause atmospheric corrosion, the enamel deteriorating in gloss and probably in colour. When the enamel loses gloss a larger surface area is presented for attack, and the rate of corrosion is accelerated. For this reason alone enamels should be fully fired to develop maximum gloss and present the minimum surface area. When atmospheric attack has reached a fairly advanced stage a white powdery scum appears on the enamel surface; this consists of silica and other insoluble constituents which are not leached out and washed away by rain. It is possible for an enamel of the non-durable type to be removed completely by three months' outdoor exposure in an industrial area, but conditions vary so much that the same enamel might last for a year or more in another locality.

Exposure indoors out of direct contact with the elements usually has a much less severe effect on enamels than outdoor exposure. The only enamels which are affected to any appreciable extent are those formulated to mature at very low temperatures without regard to durability. Under normal conditions even these acquire only a slight iridescence due to the formation of a thin film of lead sulphide on the surface. In industrial areas, however, where much hydrogen sulphide may be present in the atmosphere, this iridescence may develop eventually into a brown film having a definite adverse effect on the brilliance of colour of the enamels.

Enamels may be attacked by acid fumes emanating from packaging materials. Sulphites used in the bleaching of paper, and chlorine and sulphurous acid used in sterilising straw, have been known to attack the enamel surface of decorated glassware, but this corrosion is usually superficial. The more resistant types of enamel in use today are seldom affected.

Enamels may be attacked by alkaline solutions used in cleaning and sterilising milk, soft drink, and beer bottles, and hypodermic syringe barrels. The attack of enamels by alkaline solutions increases considerably as the temperature of the solution is raised, but raising the concentration of the alkali does not increase the rate of attack nearly so much as might be expected. Alkalis generally have a more severe effect on the flux constituent of enamels than on the colouring pigments. The silica and other acidic constituents of the flux are dissolved, so there is no white incrustation on the enamel surface as in atmospheric weathering and attack by acids. The most obvious effect of alkali attack is the removal of gloss. After this initial stage the enamel is gradually reduced in thickness until it is completely removed. Thus, an enamel is not completely spoiled as soon as it is appreciably attacked by alkali, as it might be by acid or atmospheric corrosion. Enamels on beverage bottles subjected to drastic cleaning with hot alkali solution often have a useful life after they have been quite severely attacked since the label is still quite legible.

Enamels are liable to attack by a variety of organic acids. Enamelled milk, cream and yoghurt containers may be corroded by lactic acid found in decomposed milk products,

soft-drink bottles and tumblers by citric and tartaric acids contained in lemon and orange drinks, and enamelled table and cooking ware by vinegar and fruit acids. The pigment constituent of the enamel is in many cases more readily attacked by acid than the flux. In some cases the colour bleaches soon after the ware is immersed in acid, although the enamel still retains its gloss and is not reduced in thickness. The flux eventually breaks down by selective attack of the acid on the basic constituents, leaving a white residue of insoluble silica.

Enamels may also be damaged by abrasion by unsuitable cleaning techniques, or by bottles coming into violent contact with each other during sorting and cleaning operations and during transport. In some modern bottle designs the risk of abrasion is minimised by providing a recess in the bottle for the enamel label. Attack by acid or alkali is accelerated if the enamel surface is abraded at the same time.

Fine hair cracks may be produced in enamels on lampshades and cooking table-ware by thermal shock. These cracks normally occur only if there is a considerable difference in thermal expansion between the enamel and the ware. They absorb dirt and moisture and cause deterioration of the decoration.

#### **4. THERMAL EXPANSION**

It is obviously necessary that enamels should match, at least approximately, the thermal expansion of the glass base on which they are to be applied. This is especially important for lamp-shades, table and cooking-ware which will be exposed to thermal shock, and for bottles for carbonated drinks which have to withstand mechanical shock and internal pressures.

The normal opaque glass enamels are heterogeneous mixtures of refractory particles suspended in a glassy matrix. They show a marked degree of elasticity, and will tolerate considerable differences in expansion without harmful effect.

Transparent colours, however, by their very nature must be completely vitreous or glasslike. Expansion factors in the case of these enamels must be more closely controlled to that of the glass itself. The same is true for crinkle ices which are applied in thick layers especially if used in conjunction with a transparent enamel to give a high relief effect.

With the limitations imposed upon us regarding colour and fusibility it has not yet been found possible to formulate enamels with low thermal expansions comparable to that of borosilicate glasses with expansions of  $33 \times 10^{-7}$ . Enamels are successfully used on these glasses however by keeping the enamel layer very thin and by foregoing some of the gloss.

#### **ENAMELLING PROCESSES**

The object of the decorator is to apply a coating of powdered enamel onto all or part of the glass and then to fuse it permanently to the glass by passing it through the lehr.

Methods used to achieve this objective are many and varied and will be discussed briefly since most of you will be already familiar with them. There are also data sheets available which cover in detail the main forms of application.

### 1) Air gun Spraying

This process is most popularly used where overall application of colour is required as for lightingware, oven ware, cosmetic jars and building panels.

The enamel powders are mixed to a fairly thin cream with a liquid vehicle or medium, and atomised by air pressure through a fine jet in a spray gun. The control of the particle size of the enamel by the colour maker, and of the viscosity of the spraying paste by the enameller enable particularly smooth and even coatings to be applied.

### 2) Screen printing

Whilst this process may be used for overall coverage its main use is when selected areas only are to be covered with one or more enamels to form a design or a label. The cylindrical shape of beverage bottles, drinking glasses and cosmetic containers is ideally suited to decoration by screenprinting.

The enamel, mixed to a thick paste with an oily medium, is forced through a screen mesh, parts of which have been blocked off leaving the required design open. The screen, originally woven silk, is now more normally made from synthetic fibre or stainless steel.

The development of thermo-printing compositions has greatly increased the usefulness of screen printing as a quick and economical method of enamelling. The powder enamel in this case is mixed with a wax-like composition which is solid at ambient temperature but fluid at higher temperatures around 70–75°C. It is necessary therefore to heat the screen directly or indirectly to 70–75°C when the wax medium melts, causing the paste to become fluid and behave like a cold screening ink. As soon as the molten paste meets the cold surface of the glassware it sets or freezes immediately giving the impression of instant drying. This characteristic gives obvious advantages such as:—

- (a) facility to print several colours without interstage drying
- (b) ability to print "wrap around" designs, going right around the circumference of the bottle
- (c) instant handleability without the danger of smudging.

### 3) Decals or Transfers

The screen transfer has certain advantages over the direct screen process. A design can be printed in many more colours than is practicable by direct screening; definition of the design and registration of the colours is better and transfers can be applied to ware which, owing to its awkward shape or curvature, is unsuitable for direct printing. Transfers can be applied by hand, using unskilled labour without the use of costly plant or machinery.

The direct screen and transfer processes are to some extent complementary, since simple designs in one or two colours can be efficiently and probably more economically applied by direct screening, and more intricate designs in a larger number of colours to give a superior decorative effect can be applied by screen transfers.

## MEDIA

Whatever the method of application the powder enamel must always be mixed with a medium or carrier suited to the particular process. During the firing of the colour all parts of the medium must have volatilised or oxidised *before* the enamel itself begins to fuse. If any organic material remains in the enamel after this point it will try to escape later through the molten enamel causing bubbling and discoloration.

Pure water is obviously the least troublesome medium from the point of view of "burning off" since after drying there is nothing left to burn away. Unfortunately, except for the very simplest airgun spraying where the article does not need to be handled, it does not have any other of the characteristics we are looking for such as adherence, transferability, hardness after drying enabling handling or overprinting etc. Materials we have to incorporate in various media to give these desirable characteristics are carefully selected and tested to give the quick, clean burn off which is so essential particularly with the lower fusing enamels and for the quicker firing schedules.

I apologise if I seem to labour this point but it is probably the most important point of all glass enamelling and the aspect in which it most differs from decorating with paints or organic lacquers. In the latter case resins, gums, etc., remain in the finished product. In the case of ceramic enamelling, having used the oils, gums and resins to get our layer of powder onto the article, we want them all to disappear leaving the clean powder to fuse onto the ware by itself, unadulterated by any residues from the media.

## THE FIRING PROCESS

At this point it is convenient to discuss the firing operation, since it is a most important stage common to all the processes of decoration. The firing operation is necessary to fuse, or vitrify, the enamels, rendering them hard, glossy and durable, and bonding them securely to the ware. The temperature at which enamels are fired is governed by the size, shape and thickness of the decorated article, and the type of glass from which it is made. Special enamels are now provided for many types of glass, and in general they should be fired at as high a temperature as the glass will withstand without softening or distorting. This temperature is normally between 500° and 620°. Lead crystal and soft soda-lime-silica glasses are fired near the lower end of this range, and the hard soda-lime-silica and borosilicate, or heat resisting, glasses near the upper part of the range.

The furnace atmosphere should be oxidising at all stages of the firing process to avoid reduction of the enamels, which contain a high percentage of lead oxide. This is especially important between 300° and 450° in the heating-up stage, since it is in this range that combustion of the organic binder in the enamel film takes place. The resultant carbon must be oxidised completely before the enamels vitrify, otherwise it reacts with them, causing discoloration and bubbling which ruin the decoration.

Electrically heated furnaces are strongly recommended for firing enamelled ware, since there are no products of combustion of the fuel as in the case of oil or gas; but whatever the method of firing, the importance of adequate furnace ventilation cannot be over-emphasised.

An ideal firing curve is illustrated for thick walled beverage bottles peaking at 610°C.

A typical cycle for thinner walled tumblers would follow a similar pattern but would go to only 560°C maximum and could be speeded up to perhaps 90 minutes throughput.

In addition to the conventional firing we have been discussing, there are several variations employed for special types of glassware such as:—

**a) Toughened or tempered glass**

For heat toughening, sheets of glass are introduced into a furnace at 640°C – 670°C for a period of 3 to 6 minutes depending on the thickness of the glass. They are then withdrawn and quickly chilled with blasts of cold air. This heat treatment sets up compressive strains in the glass surface and thus makes the glass very much stronger both to physical impact and to thermal shock.

If the glass is required to be enamelled – for building panels or cooker fascias panels – the enamel is applied by screening, spraying or roller coating and fired on as the glass receives its heat treatment necessary for toughening. In other words we fire the enamels at no extra cost.

**b) Bent glass**

Another heat treatment carried out on glass is that of heating flat glass until it softens and sags into the shape of a metal mould. Again the temperature required is around 650°C and the time 4 to 8 minutes depending on the span or diameter of the mould, and the depth to which it is desired to be bent. Large shallow bends require less heat and time than small deep dishes. Here again we fire the enamel free of charge concurrently with the heat treatment.

**c) Very thin walled glasses** such as are in use for ampoules and lighting bulbs will withstand very severe thermal shock and so may be fired very rapidly. In the case of light bulbs one factory in the U.K. is re-packing them in cardboard boxes within 5 minutes of putting them onto the automatic spraying machine. The actual time taken to pass through the Lehr is only *1¼ minutes*. The furnace temperature is about 650°C but ware passes through so rapidly that the outer surface just reaches around 600°C, sufficient to fuse the enamel without allowing time for the heat to penetrate through the glass and cause it to distort.

In these special cases of toughening and bending glass, the colour manufacturer cannot recommend the enameller to fire 'a bit higher' or 'more slowly' since the firing cycle is set by the requirements of the heat treatment. He must formulate the enamels and media to suit the firing schedule.

## MIXABILITY OF ENAMELS

Although many enamel colours can be intermixed it cannot be assumed that one will arrive at the intermediate shade one would expect when mixing water paints or oil paints in an artist's paint box. For example one could mix a red and a white hoping to achieve a pink tone. This mixture would indeed be pink in powder but on firing, chemical interaction between the two colours could result in a grey black colour.

The reason for this particular poor result is that we have mixed a cadmium red with a non-cadmium white and the two are not compatible. The bright yellow, orange and red enamels pigmented by cadmium sulpho-selenides require the presence of cadmium in the frit to stabilise the pigment. If mixed with a non-cadmium frit the pigment breaks down to the dirty grey black.

Some years ago my company saw the advantage to the enameller of having a palette of colours which were completely intermixable and which would enable him to obtain a very wide range of shades from seven basic colours. This led us to introduce our "Mixable colours for glass".

The red A and deep yellow B are cadmium pigments and therefore require to be based on a cadmium frit. The five other colours including yellow C which is pigmented with lead antimonate (Naples yellow) do not need cadmium in the frit and are normally made with non-cadmium frit. However, so that they may be mixed with the bright red and yellow which *do* require cadmium frits, for the mixable ranges we base them also on cadmium containing frits.

*N.B.* The cadmium incorporated in the frit has no pigmenting effect. The titanium white is just as white whether it be in cadmium containing or cadmium free frit.

Finally I should like to mention a method of decorating or marking glassware which is not strictly enamelling, but which employs similar application methods and firing techniques to those used in ceramic enamelling.

## AMBER STAINS

Amber stains are based on silver compounds which migrate into the surface of the glass during firing at temperatures between 450 – 550°C. Colours ranging from pale yellow through amber to dark brown can be obtained depending on the composition of the glass, the temperature and duration of firing and the particular stain employed.

In order to establish the correct conditions for the colour and intensity required, the decorator is recommended to make tests at various firing temperatures. Generally the longer the duration of the fire and the higher the temperature the stronger will be the colour produced. There comes a point, however, at which the stain ceases to improve in colour and starts to become weaker again. A blue iridescent colour accompanied by a milky, opaque appearance of the glass surface after firing indicates that the glass has been overfired and a lower temperature should be employed.

After firing, the iron oxide used to carry the stain can be removed from the surface of the glass by brushing or washing. The stain remaining in the glass is permanent and can be removed only by polishing away an appreciable depth of the glass itself.

This quality of permanence makes this type of stain ideally suited for marking laboratory apparatus and this is where it finds its main use. Unfortunately silver compounds are the only materials which will migrate into the glass in this way so that we cannot offer other colours such as green, blue etc., by this method.

This paper was presented at the Symposium 1974, held at Lancaster University. Grateful acknowledgement is made to the author and to Blythe Colours Ltd.

# NEWS

## FROM

### SOUTHERN SECTION

Southern Section Meeting at C.E.R.L. (Leatherhead) at 7.30 p.m. on Wednesday 14th May, 1975.  
Lecture "Glass Forming" by Mr. Alan Strand, of Hirst Research Labs, G.E.C./A.E.I.

It was a superb setting and ideal for a glassblowers meeting that 12 members of both the Southern and Thames Valley Sections met at C.E.R.L. for a lecture of glass forming by Mr. Alan Strand.

He began his lecture by showing slides of different pieces of glass apparatus which had been formed in graphite moulds to the desired shape (Graphite EY9). He stated that for experimental purposes graphite was better than cast iron moulds because they were cheaper, could be modified and the glass did not stick. However, graphite moulds had a much shorter life than cast iron. We saw slides and examples of various shapes of Cathode Ray Tubes, square, flat and conical shapes. Various shapes of glass tubing and a whole range of mould-ware including medallions, ornamental glass shapes.

He showed us glass catheter moulds, which in turn were made on graphite moulds. These catheter moulds would form very fine to quite large plastic catheters for various uses on the body.

We saw details on the centrifugal valve base moulding machine, in which glass and metal pins were placed and sealed by heat and centrifugal force. Gas heaters were used and a speed of approx. 200 rpm. To avoid oxidation the chamber was filled with Nitrogen gas, eliminating wear on the graphite moulds.

In all, we had a particularly interesting lecture with many slides illustrating the work done.

Several questions were asked and much interest aroused.

Details of special moulds for any shape: Fordath Engineering Co. Ltd.,  
Carbon and Graphite Division,  
Brandon Way,  
West Bromwich.

Mr. Fred Luadaka gave a vote of thanks, and the meeting adjourned for coffee and refreshments at 8.30 p.m. Our thanks go to Fred and Peter for their hospitality and to C.E.R.L. for their facilities.

**Meeting at Surrey University on Saturday May 17th.** The following report is submitted by Fred Luadaka:

A mini Symposium was held at Surrey University, Guildford on Saturday, May 17th, to which 24 members from T.V. and Southern Section attended. There were three lectures booked, the first of which was to have been given by Stan Fussey, but he had to withdraw at the last minute and Ron Mason stepped in to give Lecture 1 on Glass Transfer Tape, manufactured by Vitta Corporation of U.S.A.

He illustrated the technique used for transferring the tape to the glass to be sealed and the technique he developed for laser tubes using vacuum as a means of applying pressure for subsequent joinings; thus a number of Brewster Angles could be incorporated in one tube. A different tape is manufactured for use with quartz.

Lecture 2 was given by Mr. Bradley of Corning, on Glass Ceramics. Firstly, he showed a film on Glass Technology. He then spoke on the diversity of glass, and how the demands of progress were met by the research department in producing the many types of glass required. There were many samples of these different glasses and glass ceramics passed round. One in particular was the glass/ceramic exhaust filter extruded to a honeycomb to be used in the car industry.

Lecture 3 was given by Rex Garrard on the history and progress of the Journal, including costs and possible means of recovering some of the cost were suggested from the meeting. Mr. Garrard emphasised the need for more members to send in material for the Journal and also paid tribute to Mr. I.C.P. Smith for his earlier work on the Journal.

At the conclusion of the Symposium, the opportunity was taken to discuss the 1976 Symposium, which was to be International. Mr. Harvey took the Chair, and informed the meeting of the progress made in this direction. It was agreed that a Symposium Committee be formed to get this project off the ground and that this be formed jointly with the T.V. Section.

Finally, thanks were recorded to the T.V. Section for arranging the meeting so successfully, which indicated that maybe more of these could be the answer to some of the attendance problems.

Ron Newman.

ABSTRACTS 'GLASTECHNISCHE MEDEDELINGEN' No. 1, March 1975.

- Hoe staat de vlag ervoor? (editorial) 1 p.  
A kind of pep talk to stimulate editorial contribution from the 'field'.
- Nabeschouwing "Glastechnische Dag 1974" (J.C. Schepers, Eindhoven, 13 p., 25 fig.)  
A review of the 'Glasstechnical Day 1974', held at Utrecht November 1974 is given, containing a survey of commercial contribution with photographs of standholders and visitors.
- Proceedings 1974 of the Nederlandse Vereniging voor Glasinstrumentmakers NVGI (Neth. Soc. for Glassblowers), 1½ p.
- Announcement of a 'Discussion Day' at NIZO-Institute at Ede (Gld) on the drawing and application in G.C.-columns of glass capillaries, ½p.
- Electrically operated manipulator for the use in vacuum (H. Kuster and P.J.M. Peters, Eindhoven, 3 p., 2 fig.).  
A description is given of a device with which a sample can be transferred from one vacuum compartment to another whilst vacuum conditions are being maintained.
- Proceedings of Kontaktgroep 'Zuid' voor Glastechniek (Southern Group of G.bl.), 3½ p., 7 fig.
- Announcement for the examination 'second level' glassinstrumentmaking 1975, ½ p.
- Examination 'Glass B' (second level) glassinstrumentmaking in 1974: theoretical and practical, 6 p., 4 drawings.
- Index G.T.M. year 1974, 3 p.
- Review of events 1975, 1 p.
- Note on Jubilee Symposium at Leiden, May 1975, ½ p.
- Information:
  - Stainless steel tubing, lined with borosilicate glass (Australian product).

Van der Burgh.

**STICHTING GLASTECHNIEK  
(Holland)  
ABSTRACTS 'Glastechnische  
Mededelingen', Vol. 13, No. 3  
July 1975**

- Glass vacuum connections, (*R.J. Brunfeldt, 3p., 3 fig.*).  
From 'FUSION'.
- What do we do about it ourselves? (*3p.*)  
Deals with the co-operation 'scientist — maker' and gives a short analysis of present day's development in the 'trade' due to outside influences. 'Permanent education' is stressed and the individual part one can play therein. A kind of peptalk and publicity for G.T.M.
- Construction and application of a vacuum jig, (*J.P.M. van Hooff, Eindhoven, 2p., 2 fig.*).  
Describes a versatile fixing block with vacuum fastening of the work. The working area can be limited with the aid of several valves.
- Stichting Glastechniek, Proceedings 1974 (*Secretary, 2p.*).
- Glasstechnical Day 1974 seen from another angle, (*H. Th. Scheepers, Eindhoven, 2½p., 1 fig.*).
- Personalia, (*½p.*)  
Note on Mr. J. de Vries on leaving the editorial group of G.T.M.
- Discussion Day, (*1p., W. Jezeer, Schiedam*).  
A report is given of a demonstration day on drawing various capillaries.

- Symposium 'Instrument Making and Science', (*J.Th. Heekstra, 5p., 6 fig.*).  
This symposium was held at Leyden University as part of the 400th anniversary of this university at the physical laboratory and was sponsored by the 'Vereniging tot Bevordering van de Opleiding tot Instrumentmaker', 'Nederlandse Vereniging voor Experimentele Instrumentbouw' and 'Stichting Glastechniek'. For the first time a symposium was organised as a result of co-operation between societies in the metal and glass field. On this occasion two 'Van Musschenbroek Medals' were awarded to Mr. Kuipers and Mr. Heubers for their merit respectively in the glass and metal world. Prof. Van den Handel read a paper on the historical background of the 'instrumentmaken', whereafter three more papers were read.
- Vacuumtechnics, part 3, (*C.J. van Klink, Leiden, 4½p., 4 fig.*).  
A continuation on vacuum pumps and characteristics.
- Book review, (*1p.*).
- Symposium S.G.T. at Delft, November 22nd, 1975, Programme.
- Glassblowers Society 'Groep West', Annual Proceedings 1974/1975, (*½p.*)

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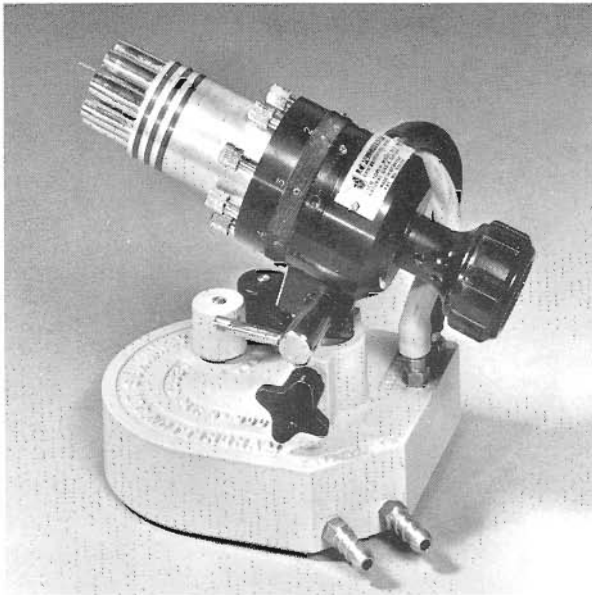


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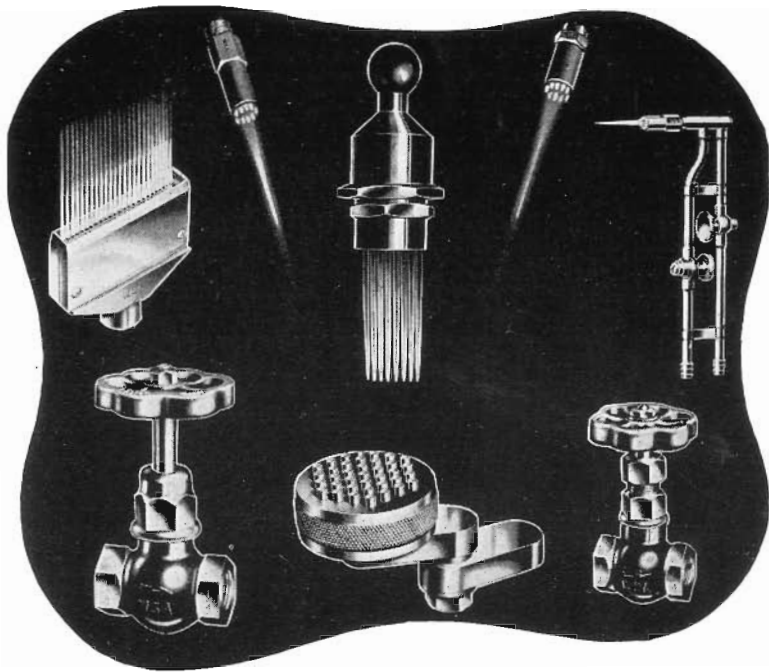
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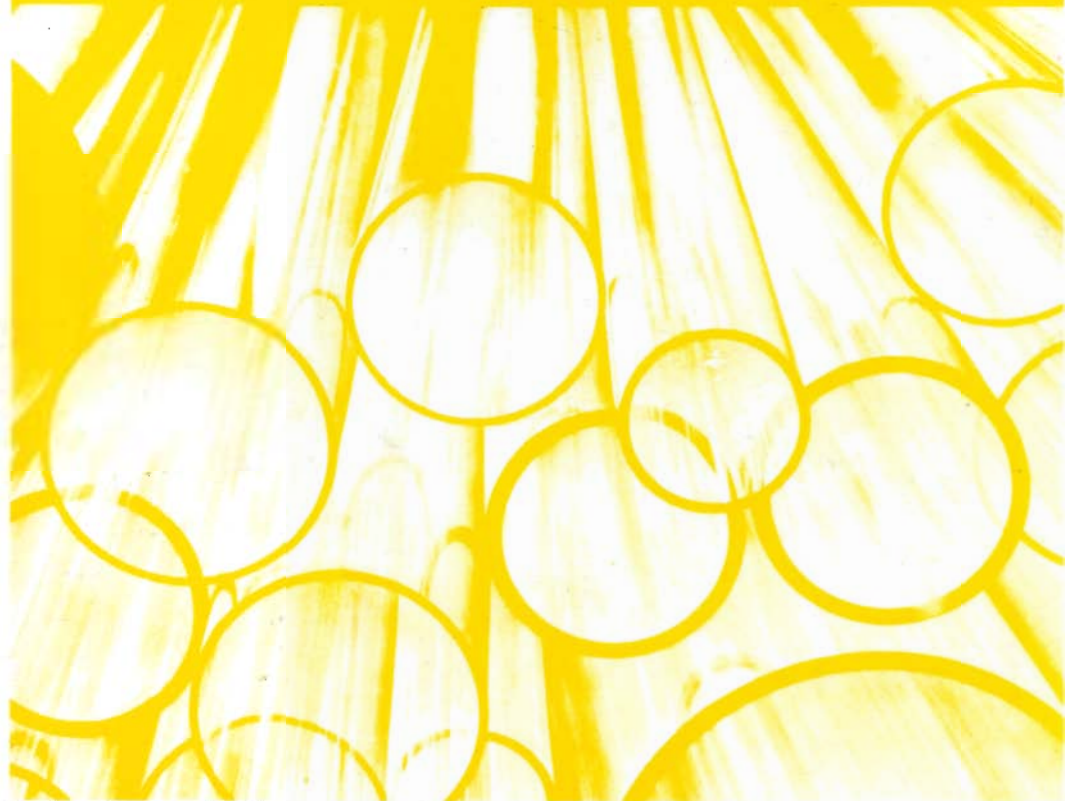
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