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Furnace Design and Temperature Control

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1 INTRODUCTION

This paper discusses the design and control of furnaces for use at specimen temperatures above 1200°C. In practice, the specimen temperature is always lower than the heating element temperature and a difference of 100°C is not unusual. Since conventional base metal heater wires such as Nichrome V and Kanthal A1 are limited to a maximum wire temperature of about 1300°C, these materials are not considered here.

The paper surveys:

(1) the range of resistance wires that may be used in constructing high temperature furnaces;
(2) conductive ceramics that may also be used as heaters;
(3) high temperature insulation materials.

The overall design of furnaces is then discussed and finally the control of temperature.

2 WIRE-WOUND RESISTANCE HEATER MATERIALS

2.1 Platinum alloys

Platinum alloys have long been used for the manufacture of small high temperature furnaces since they have the two advantages that the wires are more or less stable in air for long periods, and many of the alloys are easily

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workable. Against this, the alloys are very expensive (although the recovered material from a failed furnace is also valuable), they are sensitive to contamination by a number of substances, and they are not *completely* stable in air but do form a range of apparently poorly understood unstable volatile oxides at high temperatures.

The most important metal in the group is platinum itself. As a pure metal it melts at 1772°C, it is weak and has a relatively high rate of grain growth at high temperature. It is therefore usual to alloy it to raise the melting point and increase the strength. Traditionally, rhodium was used for this but over the last few years its price has increased sharply due to its use in catalytic exhaust units in cars. Broadly, alloying with the much cheaper iridium has the same effect, although it is less efficient. Properties of rhodium and iridium alloys with platinum are given in the literature (Pennellier, 1987).

Normally, platinum alloys with 10 (weight)%, 20% or 40% of rhodium or alternatively 10% or iridium are used. In practice, 40% of rhodium or about 10% of iridium represent the highest alloys that are sufficiently workable for manufacture into stable furnace windings. Currently, the 40% rhodium alloy (melting point 1940°C) costs something like 50% more than the 10% iridium alloy (melting point 1800°C). That extra 140°C is very expensive.

Pure platinum can also be strengthened by the addition of a fine dispersion of a small quantity of a stable oxide around the grain boundaries which prevents grain growth. This grade (oxide dispersion strengthened) is sometimes used for furnace winding, although the melting point remains 1772°C.

Pure iridium, with a melting point of 2447°C, appears an attractive material from which to manufacture furnace windings. In practice, it is so fragile that there appears to be no record of it having been satisfactorily used for this purpose.

The formation of unstable volatile oxides of the platinum metals is often the factor that leads to final failure of a furnace. The mechanism appears to be that very unstable oxides are formed by reaction of the platinum and alloying metals with oxygen which have a very short lifetime and decompose to form the metal and oxygen again.

If during its lifetime, the volatile oxide diffuses a significant distance away from the metal surface then it decomposes to form minute crystals of metal adjacent to but not forming part of the furnace winding. The phenomenon appears to be little understood and an attempt has been made in Fig. 1 to collect some data showing the rate of loss of metal from a number of alloys when they are freely exposed in pure oxygen: the data are meagre. Examination of the figure suggests that if a furnace was built in which the atmosphere had completely free access to the winding then the lifetime to be

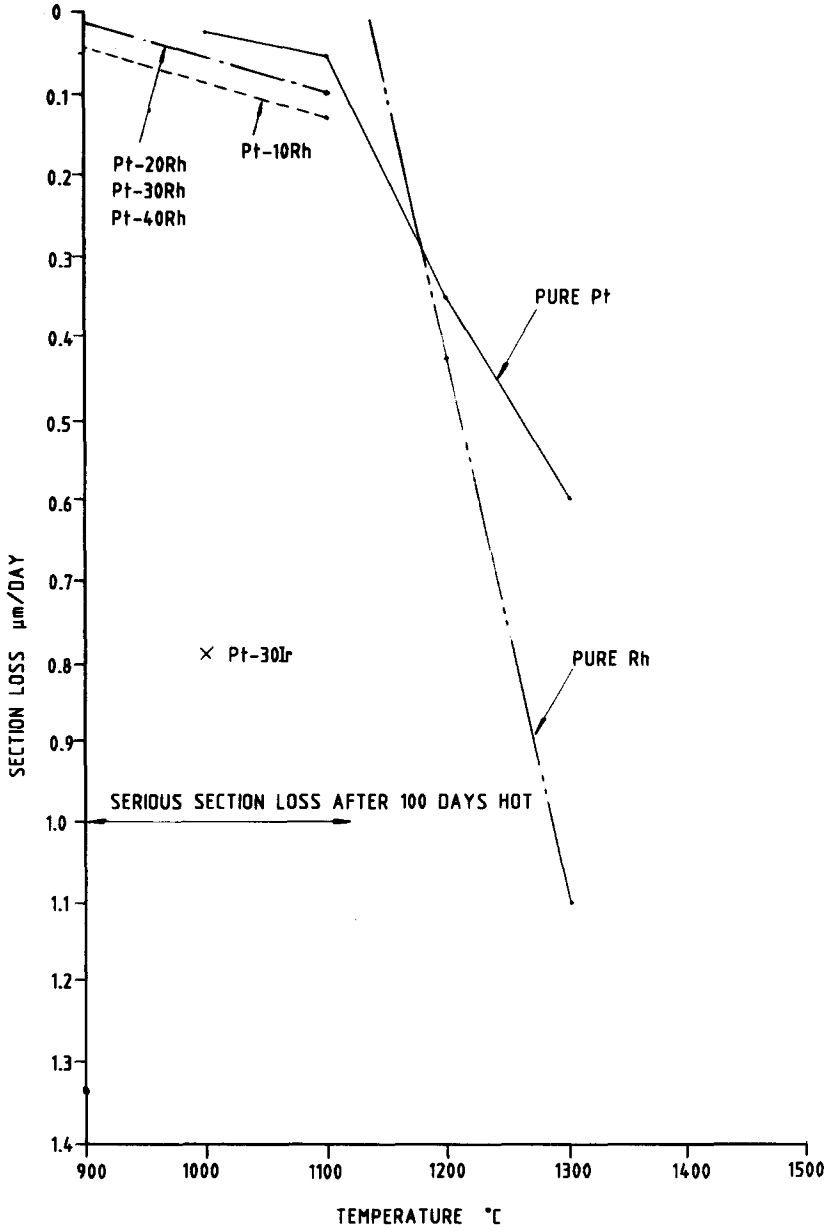


Fig. 1. Loss of material from platinum alloys freely exposed to oxygen.

expected would be short, particularly at the higher temperatures. In practice, it is usual to take particular care with platinum wound furnaces to embed the elements as effectively as possible in a relatively non porous pure cement layer to restrict air access to the metal.

With the increasing use of small platinum furnaces at high temperature, there would seem to be a good case for one of the platinum manufacturers to carry out a more detailed practical investigation of the conditions under which these alloys can best be used.

2.2 Refractory metals

Molybdenum, tungsten and tantalum are all metals which may be used for manufacturing heaters and are readily available in wire form. Their advantages are that they are strong, relatively cheap and have high melting points, but the major disadvantage that they all oxidise in air at relatively modest temperatures. Of the three, tantalum is by far the most reactive and can only be used in an atmosphere of high vacuum, or pure argon; but it is very easily workable. Tungsten has the highest melting point (3410°C) and is the most stable, but molybdenum (with a melting point of 2620°C) is nearly as stable and is more readily workable. The most sensible use for these for ceramic testing at high temperatures is for the testing of non-oxide ceramics in oxygen-free conditions. Thus, testing silicon carbide at high temperatures in pure argon will eliminate effects due to grain boundary oxidation. It is also advantageous to test silicon nitride in pure nitrogen at temperatures where there is a significant dissociation pressure of nitrogen. In these cases, the pure argon or nitrogen atmosphere will protect tungsten or molybdenum heaters. Under these circumstances it is usual to employ a 'cold wall' furnace, in which the heater, the insulation and the specimen are all inside a relatively cold vessel made from stainless steel.

Both molybdenum and tungsten are completely compatible with recrystallised alumina (as an electrical insulator) at temperatures up to 1900°C. In addition to the pure metals various grades are available which are either oxide dispersion strengthened or alloyed to retard grain growth and recrystallisation and give a more creep resistant alloy at high temperatures.

3 CONDUCTIVE CERAMIC RESISTANCE HEATER MATERIALS

Generally all these materials are brittle when cold and are not available in wire form but only as rods or tubes.

3.1 Silicon carbide (Fig. 2)

Silicon carbide can be used to a maximum temperature of about 1600°C in air, but rather lower in other atmospheres (Kanthal Ltd, 1987). Its main advantages are that it is relatively cheap and is available in a wide range of standard and non-standard sizes. Its main limitations are that grain boundary oxidation during use causes an increase in resistance and embrittles and weakens the heaters. Since a number of silicon carbide heating elements are generally used in any one furnace, then for a fairly old set of heaters failure or breakage of one generally means that a complete set has to be replaced to ensure matching resistance. A second limitation which may be of importance but is often not realised is that the elements are normally glazed with aluminium calcium silicate to reduce their oxidation

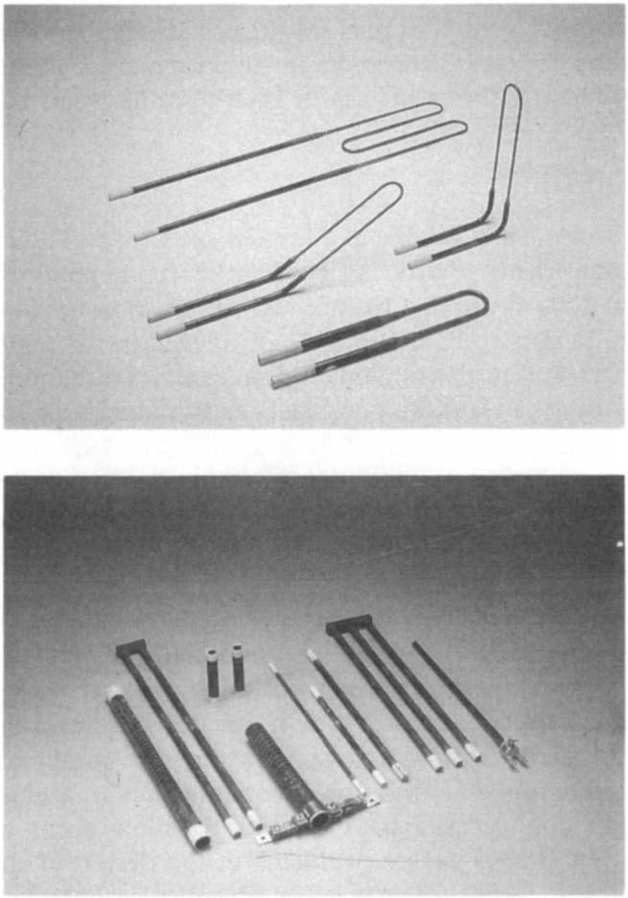


Fig. 2. Examples of SiC and $MoSiS_2$ heating elements.

rates, and at high temperature the glaze can evaporate onto the testpiece or surrounding refractories to such an extent that their properties can be adversely affected. Despite these two limitations, it is a most useful and versatile heater material.

3.2 Molybdenum disilicide

Molybdenum disilicide can be used to a maximum temperature of about 1800°C in air, and rather lower in other atmospheres (Kanthal Furnace Products, 1984). A 1900°C grade is just (1988) becoming commercially available. The material has a very large temperature coefficient of resistance, which necessitates care in the design of control equipment, although in simple cases the feature can be a help since it acts as a self limiting power control. Technically it has more limitations than silicon carbide in that it is very brittle when cold and relatively weak when hot, and for this reason is generally used vertically as 'hair pins'. Multiple hair pin forms are available, but the necessity for adequate support for mechanical stability at high temperatures tends to limit their use to 1600°C rather than 1800°C.

3.3 Lanthanum chromite

Lanthanum chromite is available in a limited range of rod and tube forms under the trade name Pyrox. If used near its maximum operating temperature of 1800°C, it must be in a vertical position because of its low creep strength. It also needs about 10% of oxygen in the atmosphere for thermodynamic stability. Chromium oxide and some lanthanum oxide tend to evaporate from the elements onto specimens and adjacent refractories. For small mechanical testing furnaces it is difficult to see any significant advantage over molybdenum disilicide.

3.4 Zirconia

Zirconia (stabilised with either calcium or yttrium oxide) in the form of rods or tubes is probably not yet a viable heater material. The main problem is its very large negative temperature coefficient of electrical resistance, which is so large that at modest temperatures it is effectively a good electrical insulator. The result is that auxiliary heaters of more conventional construction are required to raise the zirconia heaters to a temperature at which they will conduct sufficient current to allow them to dissipate significant power. It also causes problems in the design of the electrical connections, since clearly these must be very considerably cooler than the main part of the furnace.

3.5 Carbon

Carbon as a heater material has the two advantages that it is very cheap and may also be machined to accurate shapes. One limitation is that it has a very low electrical resistance and therefore requires high currents, which can lead to problems of electrical connection. Since it is readily oxidised in air, the heater must run in an inert atmosphere or vacuum.

4 INSULATION MATERIALS

There exists a wide range of insulation materials for hot-face insulation for use above about 1300°C. The main types are ceramic fibre in either a bulk or fabricated form, insulating brick or loose powder fill. In principle, all of these trap air under conditions where there is little convection so that the minimum possible conductivity is that of still air. In practice, the solid material conducts some heat so this limiting value is never achieved, and also radiation is of great importance, so that quoted values of thermal conductivity in fact include a major component due to internal radiation. It is largely this feature which causes the quoted 'conductivity' figures to rise rapidly as the temperature increases. There is as yet no alumina or alumino-silicate equivalent of the micro-porous silica insulation which is so effective because the 'cell' size is small compared to the mean free path of air molecules in the insulation.

4.1 Ceramic fibres

Alumino-silicate fibres are widely used for insulation at temperatures up to about 1260°C. At higher temperatures, either alumino-silicate fibres containing a higher proportion of alumina, or alternatively mixed fibres including some high alumina fibre, are used. The best known is the ICI-developed 'Saffil' fibre which is about 95% alumina and 5% silica. Pure alumina fibre is less satisfactory as an insulation material. As with all fibrous insulation, the maximum operating temperature for any specific application is that at which shrinkage on heating at that temperature becomes unacceptable. For Saffil-based materials, this is usually 1500–1600°C. At higher temperatures, materials based on stabilised zirconia fibre may be used, although it is relatively heavy and expensive.

4.2 Filled ceramic fibre

A number of products are available based on alumino-silicate fibres mixed with alumina powder and some form of binder. Many of these are still in a pilot stage, and, depending on the amounts of filler and binder incorporated, the product can vary in density and strength over a wide range. The lower density materials are essentially for insulation, whereas the higher density materials are essentially high temperature structural materials.

4.3 Loose fill

Loose fillings of alumina powers have traditionally been used as the insulation in high temperature furnaces for many years. Although not particularly effective as an insulation, and relatively very heavy, suitable grades of high purity still have their uses, particularly as backing for platinum alloy windings.

5 GENERAL ASPECTS OF FURNACE DESIGN

Figure 3 attempts to summarise the different types of furnace that are normally used for testing ceramics. The following paragraphs are obviously not meant as a detailed guide to the design of furnaces but are intended to point out particular aspects of design and the uses and limitations of different types of design.

5.1 Integrated units

Although it is usual to employ a conventional testing machine in conjunction with a separate furnace, it is nevertheless possible to combine the two. This suffers from the major disadvantage that it is clearly extremely difficult to design and build a structure which is anything like as rigid and dimensionally accurate as a proper test machine frame and at the same time act as the casing for a furnace; for this reason, the use of such integrated units tends to be limited to relatively crude test frames which are used for relatively inaccurate testing, for example for modulus of rupture testing for quality control. Figure 4 shows a small integrated unit which may be used up to 1500°C in either a three-point or a four-point bending version for simple MOR type testing.

5.2 Controlled atmosphere testing

Controlled atmosphere testing is normally carried out in one of two distinct types of furnace. In cold wall furnaces, an essentially cold metal enclosure (which is probably water cooled for compactness) forms the envelope

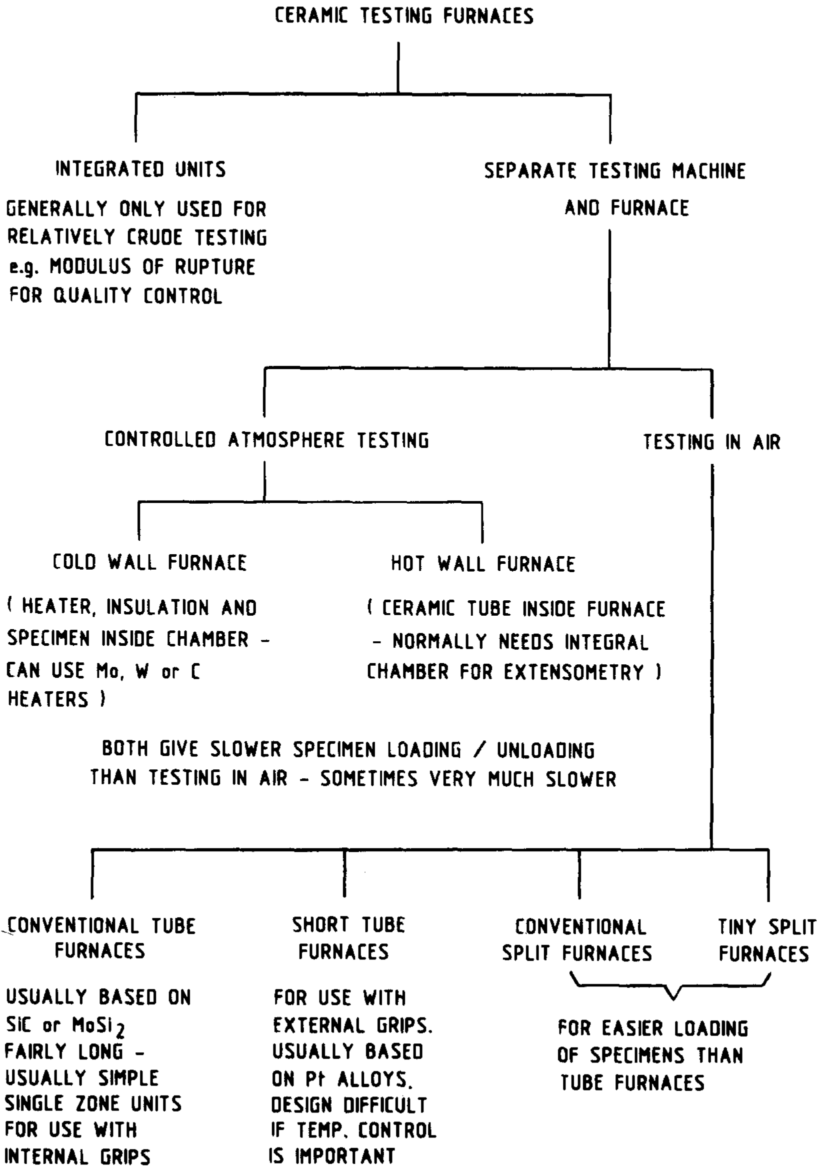


Fig. 3. Types of ceramic testing furnaces.

retaining the controlled atmosphere, and the heater, insulation, specimen, grips and normally extensometry are all inside the chamber. With hot wall furnaces, a conventional furnace running in air is fitted round the outside of a ceramic tube, inside which is situated the specimen and normally the grips and extensometry.

As an example, the small integrated testing furnace shown in Fig. 4 is built into a vacuum-tight enclosure and can be used for testing in either air or in a

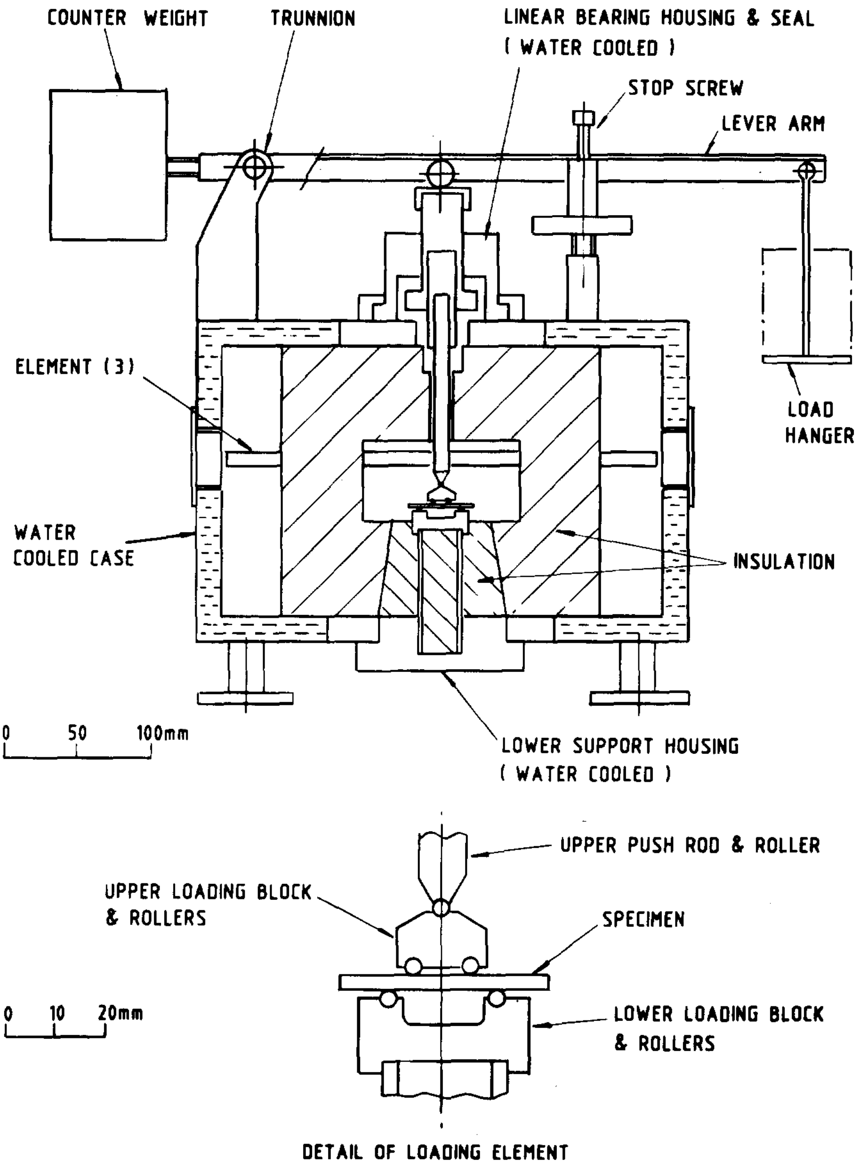


Fig. 4. Integrated high temperature furnace for four-point bend testing.

controlled atmosphere. For testing in air, the loading door may be left permanently open and the loading slot closed with a removable slab of insulation. To maximise efficiency, it is possible to change specimens between tests without cooling the furnace, particularly if specimens can be pre-heated by leaving them at the hot end of the loading slot while previous specimens are being tested. However if the unit is used for controlled atmosphere testing, a much more lengthy procedure is required and this makes the use of controlled atmospheres more attractive for long term testing. One advantage of controlled atmosphere testing is that, provided the testing atmosphere is compatible with heaters such as tungsten or molybdenum or carbon, relatively cheap heaters can be used up to high temperatures. Since many ceramics of technical interest are stable in air (and in many cases are oxides or mixed oxides) the major interest has been in testing in air. For convenience, the types of furnace used have been divided into four groups (Fig. 3).

5.3 Conventional tube furnaces

There are generally no problems with conventional tube furnaces. They are usually based on silicon carbide or molybdenum disilicide heaters, and in their design, furnace considerations normally take precedence over the grips, extensometry or specimen size. The simplest design is to make the furnace relatively long so that even a single zone furnace will give an acceptably long zone in the centre (or more usually just above the centre) where the temperature is sufficiently constant for testing. However the simplicity of the furnace design can cause significant design problems for grips or bend test jigs or extensometry.

5.4 Short tube furnaces

This heading is intended to cover furnaces which are designed to enclose the specimen only and not the grips. Normally, air cooled or water cooled metal grips are used very close to the furnace ends. The specimen extends through the length of the furnace and into the grips and is thus long compared to conventional test specimens. Long precision specimens are expensive, and hence a very short furnace is highly desirable: this causes significant problems for the designer. Because the furnaces are short, it is normally essential to have three zones, and also they are usually of small diameter since the bore has only to accommodate the specimen as the grips are now outside the furnace. With a specification such as this, platinum alloy windings are almost essential. Figure 5 shows a typical three-zone platinum alloy wound short tube furnace suitable for this type of test. Unlike conventional furnaces where the grips are inside the bore and end-losses are through the pull rods, with these short furnaces the end-losses are through the specimen only and hence are very dependent on the thermal conductivity of the ceramic. When oxide ceramics of relatively low thermal conductivity are tested, there are only a few problems with end-losses, but carbide-based testpieces with much higher thermal conductivities cause considerably more

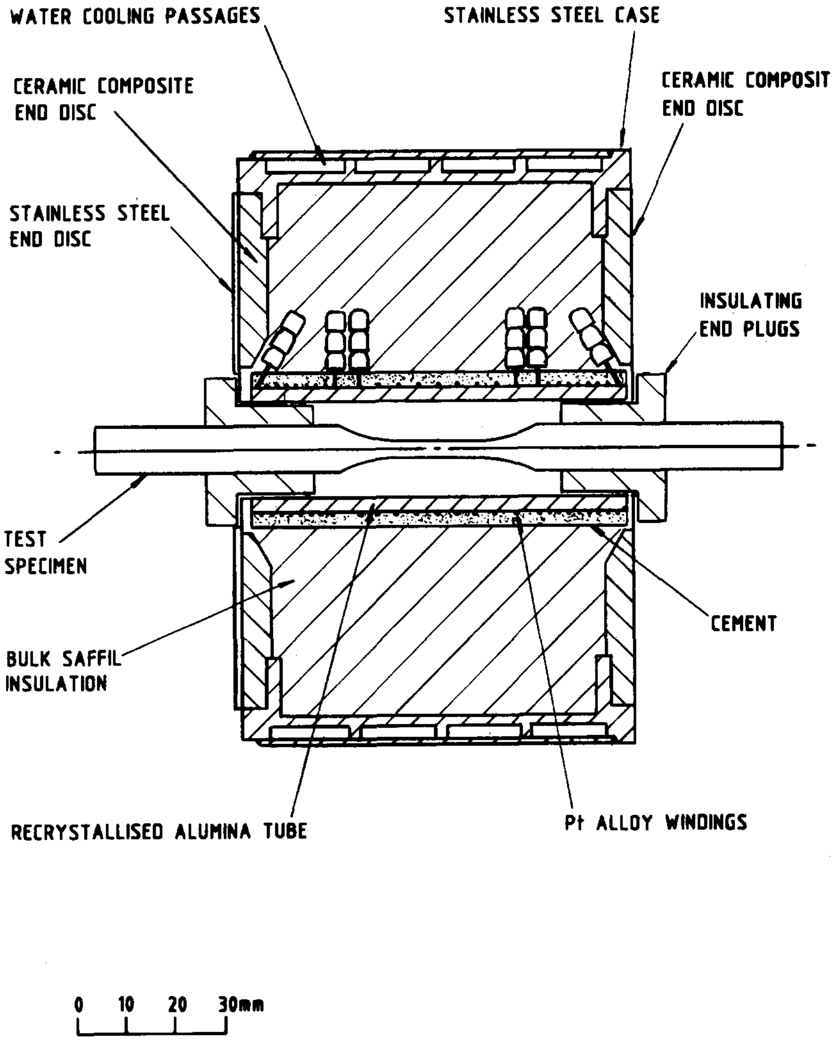


Fig. 5. Small three-zone platinum alloy wound tube furnace.

problems and these become very severe for specimens of materials such as metal fibre reinforced silicon carbide.

Figure 6 shows a cruder version of the same general type in which a very short furnace is heated by a single-zone array of silicon carbide rod elements. This type is very significantly cheaper than a platinum wound furnace, but has a very much poorer temperature profile. Nevertheless, it can have applications (for example in shear testing of pins) where the specimen extends for such a short distance along the length of the furnace that the poor temperature profile is acceptable.

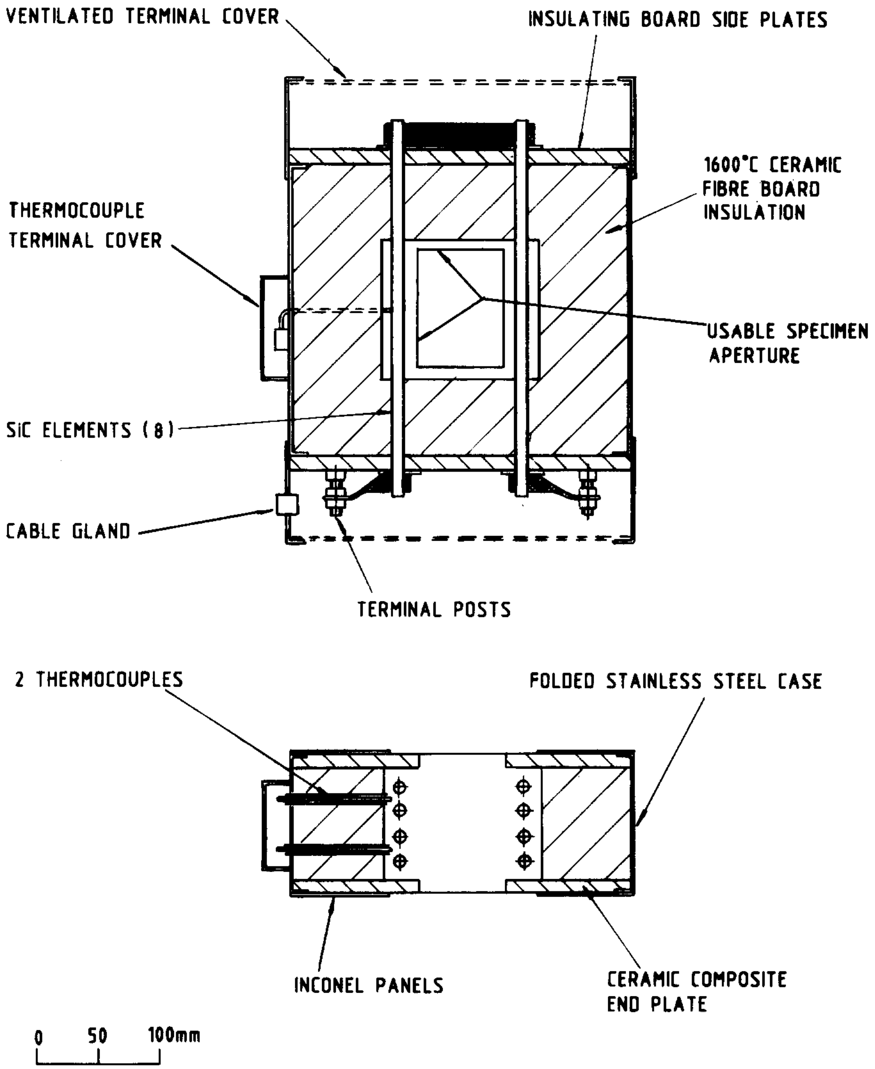


Fig. 6. Short single-zone silicon carbide heated testing furnace.

5.5 Conventional split furnaces

The only difference between furnaces of this type and those in section 5.3 is that these are split vertically so that the two halves can be moved away from the testpiece for greater ease in assembly. Indeed, in cases where the headroom on the machine is restricted, it may be essential to use a split furnace. Figure 7 shows a typical model of this type: it is a split single-zone furnace heated by molybdenum disilicide hair-pin elements and suitable for long-term use at specimen temperatures of up to 1500°C.

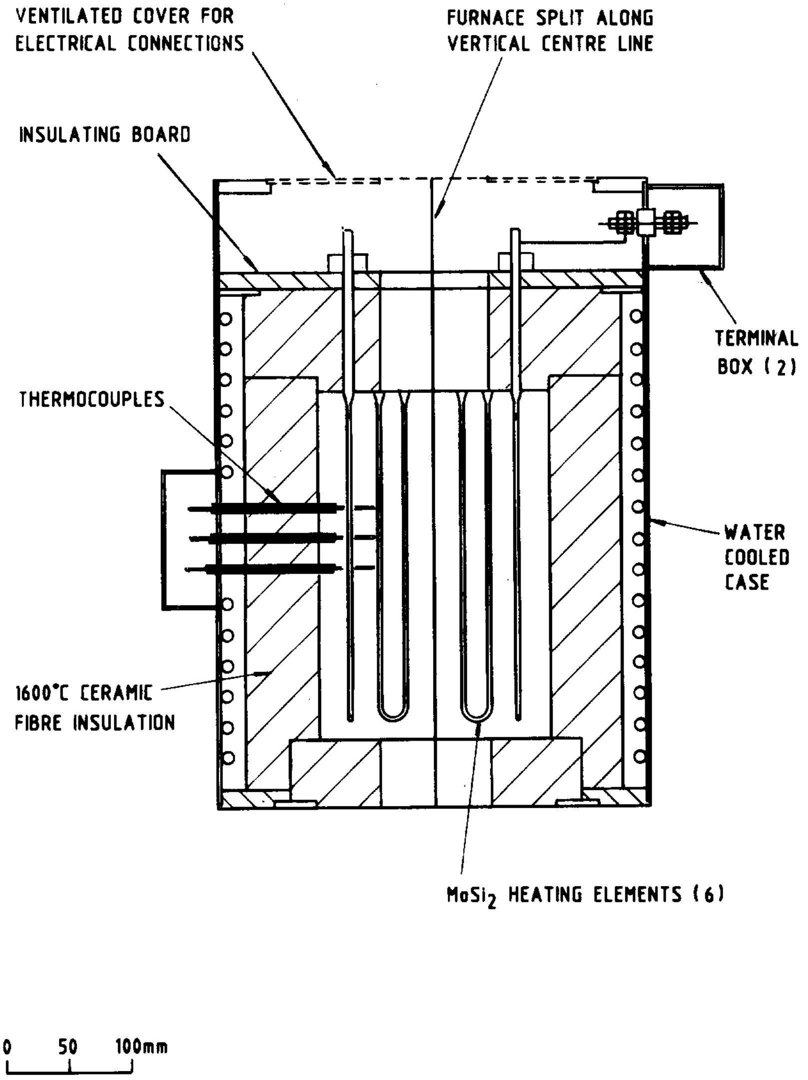


Fig. 7. Large split single-zone testing furnace.

5.6 Tiny split furnaces

These are the split equivalent of the short tube furnaces discussed in section 5.4. To give a satisfactory temperature profile combined with a long life at high temperature is a difficult task. Probably the most satisfactory approach is to use a three-zone design with platinum alloy windings. Alternatively, a single-zone design based on customised multi hair-pin molybdenum disilicide heaters may be used, although the temperature profile will suffer.

5.7 Zone requirements

Generally either one or three zones are used: theoretically, two zones are unsatisfactory. Inevitably, three zones must give a better temperature distribution than a single zone, although for routine testing under exactly reproducible conditions it is possible to make a three zone furnace initially to establish the power distribution required along the length of the furnace and then make a single-zone furnace exactly to this distribution. However, a change in the test conditions will normally change the required power distribution, so this solution has limited applicability in practice. It is probably not realistic to try to build furnaces less than about 100 mm long with three zones unless wire wound elements are used.

6 RADIANT FURNACES

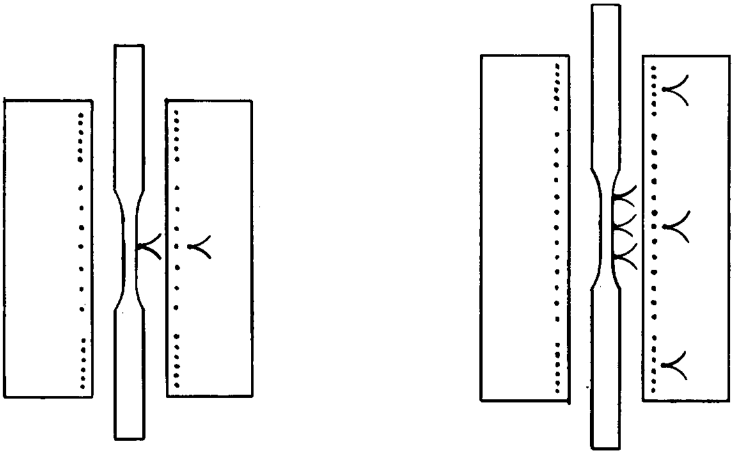
Although all the furnaces discussed to date are radiant furnaces in the sense that the predominant mode of heat transfer is by radiation, the term is normally used to refer to furnaces in which the furnace casing is essentially cool: there is no insulation, and radiant bulbs (normally tungsten/halogen) are arranged around the specimen and heat it entirely by radiation. Such furnaces can have considerable advantages at temperatures within their usual operating range. The most experienced manufacturer (Research Inc., 1988) regards 1200°C as the maximum operating temperature for mechanical testing of ceramics. Since this is the limit of the range of base metal wound furnaces, it is proposed not to discuss them in this paper for the same reason.

7 TEMPERATURE CONTROL

7.1 Thermocouple positions

7.1.1 Single-zone furnaces or single thermocouple three-zone furnaces

Figure 8(a) shows a sketch of a furnace with a testpiece in it with the usual two positions for a control thermocouple—either directly attached to the centre of the specimen or in a thermowell next to the furnace winding. For accuracy of control, the best position for the thermocouple is directly attached to the specimen, but it does have two disadvantages. Firstly, the thermocouple has to be attached to each specimen when setting up a test which takes time, and secondly, if the specimen is heated fairly rapidly, there is often a very considerable temperature lag between the specimen and the



a) SINGLE THERMOCOUPLE CONTROL

b) TRIPLE THERMOCOUPLE CONTROL

Fig. 8. Diagrams showing possible positions for thermocouples in mechanical testing.

furnace winding which can lead to a temperature overshoot and winding damage, although both of these are less likely with a properly adjusted controller.

For three-zone control using a single controller and three thyristor units, care has to be taken in the heating rates used. This is because more heat has to be applied to the end windings of the furnace than to the centre winding to compensate for the greater heat loss at the ends at equilibrium.

During heating, particularly if the heat-up rate is rapid, and there is a much larger thermal mass in the long middle zone compared to a short end zone, the end zones may become over heated if only a single centre thermocouple is used.

7.1.2 True three-zone control

Figure 8(b) shows diagrammatically a specimen in a furnace with the typical positions for three control thermocouples. For thermocouples in a thermowell in the furnace, these are placed one in each of the three-zone windings. If the thermocouples are attached to the specimen, these are shown in the idealised positions for control of the gauge length, with one in the centre and one at each end of the gauge length. Neither of these arrangements is really satisfactory. When the thermocouples are positioned next to the furnace windings, it is possible to ensure that there is a minimum temperature gradient along the furnace tube itself, but due to heat losses from the grips and pull rods this may not give particularly good control over the gauge length. When the thermocouples are positioned on the gauge length of the specimen, with the normal geometry of the furnace and specimen, the thermocouples that control the end zones are actually inside the centre zone of the furnace. This often gives unstable control, with significant oscillations of the end thermocouple temperatures.

In general, each case must be considered individually. There is no obvious simple correct answer in most cases, but thermocouple positioning is a vital aspect of temperature control.

With regard to the lengths of zones in three-zone furnaces, it is sometimes stated that ideally the end zones should be infinitely short and infinitely powerful. In practice, the power density of the zones is limited by the allowable surface load on the heating elements and on the ceramics, so that the end zones have to be of reasonable length.

As a rough rule of thumb, an end zone should be of the order of one tube diameter, unless the furnace configuration is such that the allowable length is very short indeed.

The gaps between the zones in general should be as short as practicable to avoid the possibility of cool spots developing. However, if the gaps are made too small, then the main worry is of electrical breakdown between zones. In any case, the electrical connections to the furnace must be carefully designed to avoid any unnecessarily large voltage differences between adjacent zones.

7.2 Self-tune and adaptive control for single- and three-zone furnaces (see also Cheshire, 1986)

The adjustment of the time constants within a three-term temperature controller, that is the matching of the performance of the controller to that of the furnace, is frequently a time-consuming task. Most temperature control systems have two distinctly different sets of conditions with which they have to cope; firstly, the large signal error, for example on starting a test, secondly, the small signal error such as that due to a small change in ambient conditions when nominally at temperature. Traditionally, one of two approaches has been used; either to set the time constants to perform both these functions passably well using an appropriate compromise, or to compromise completely one of the requirements in favour of the other. Considerable effort has been expended by controller designers in minimising the large-signal problems, including integral desaturation, 'four-term' control, the Eurotherm 'crossed time constants' system and latterly, approach control and process cut-back. Refinements of these techniques are continually being produced particularly with regard to the methods of 'releasing' the integral and derivative terms on starting.

Current developments in automatic tuning centre round the desirable goal of providing a high-accuracy, high-stability, high-performance controller which the user can, having made the initial configuration, 'fit, set and forget'. Two methods are currently available, both based on established tuning techniques—the 'Cohen and Coen' (or process reaction) method and the Ziegler–Nicholls (or disturbance response) method.

'Self-tuning' is based on the process reaction study. On initiating 'self-tune', the controller inhibits all action for a period, during which it investigates influences from surrounding zones, if any, memorising their effects. After this wait, the maximum allowed power is applied and maintained until the process approaches its desired value. At this point, output is inhibited and a couple of oscillations are induced. The controller is interested in a number of parameters (Fig. 9): the delay time; the rate of change of temperature with full output; the overshoot on the first switch-off and the natural oscillation period at or near the setpoint value. From these parameters, the values of proportional band (gain), integral time (reset), derivative time (rate) and approach/cutback are either inferred or calculated. This method of tuning has been designed to calculate values for systems with interactive loops—three-zone laboratory furnaces for example.

No suitable system has yet been developed which will take care of interactive loops where the sensors also are interconnected, as with the back-to-back master/slave thermocouple arrangements used in some three-zone configurations. Only the master zone may be tuned by this method.

Figure 10 illustrates 'Adaptive tuning', which is an iterative process based upon disturbance response analysis. The tuning will not trigger, having been initiated, until a 'trigger point' is reached. This trigger point is set by the user and is based upon his requirements, perhaps empirically established. Upon the tuning being triggered, the algorithm will observe the disturbance and make an adjustment of time constants as appropriate. The iterative nature of adaptive tuning means that where the initial time constants setting is excessively incorrect, the establishment of satisfactory control may take a long time. Intelligent use of self tuning plus adaptive tuning will minimise this adjustment time.

Self-tuning is normally a 'one-shot' process, whereas adaptive tuning can be left running continuously if required.

The optimising of time constants in control loops is an area where considerable effort is currently being expended due to the rapid increase in both speed and memory capacity of microprocessor-based instrumentation. Rapid development is expected in this field.

7.3 Links with computers

The use of the personal computer in industrial and laboratory applications is now widespread and the quality of ready-made software packages is now

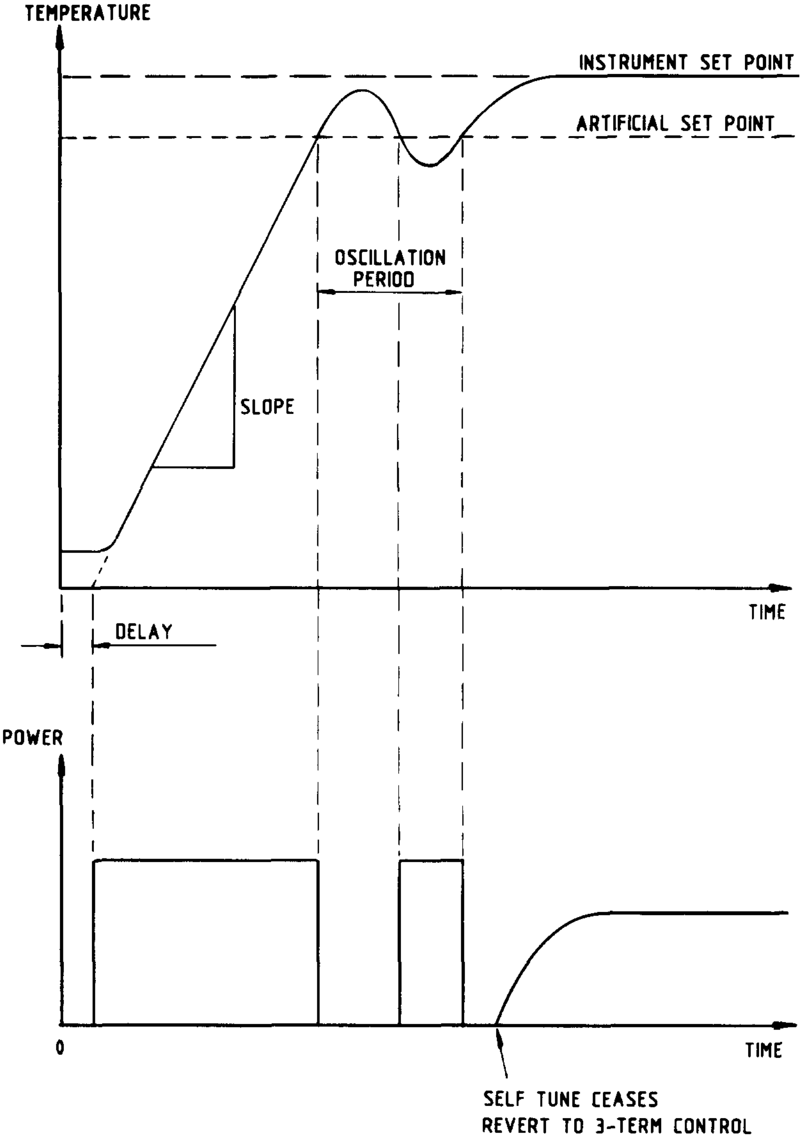


Fig. 9. Temperature response from self-tuning controller.

so high that their popularity has enabled users to obtain a very high economy of scale. The use of these computers gives facilities which previously were unavailable; of particular advantage is the retention of data and the ability to note and draw attention to changes, either while they occur or later.

Control systems which link with computers usually take one of two forms. Firstly, the compact direct digital control system; the programmable logic

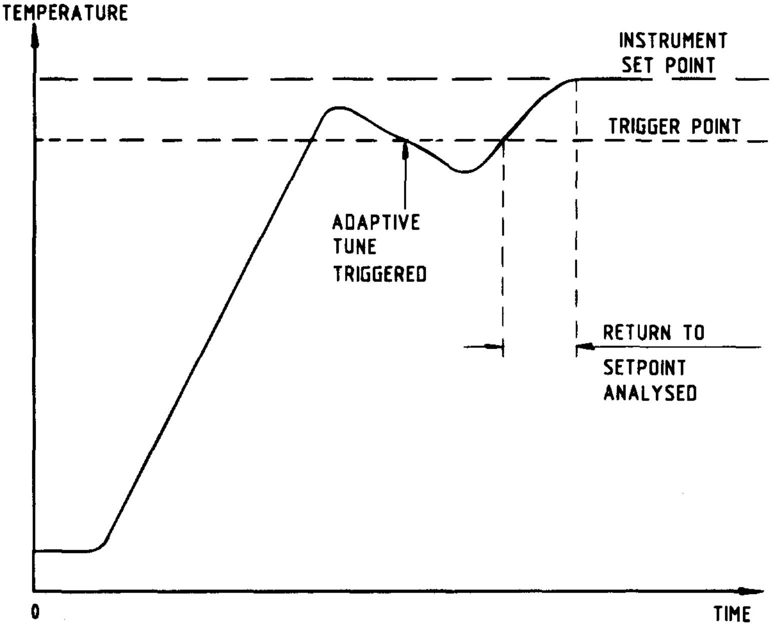


Fig. 10. Temperature response during adaptive tuning.

controller is the most popular example of this, enabling one piece of equipment to perform all control and logic functions. Secondly, and currently by far the most popular approach, is the use of the conventional single-loop controller with communications to a computer. The advantages of this latter configuration are: that it permits the continuation of any testing in the event of a computer component failure; it gives the operator a permanent local display of conditions and allows the user to perform 'off-line' tasks on his computer whilst recording the background. Modern technology permits the connection of more than one controller to a computer; successful installations of up to one hundred instruments connected to one computer port have been achieved. The additional cost of this facility is only the provision of a printed circuit card inside each controller, together with a standards converter and high-quality interconnection cabling.

The use of a supervisory computer enables the user not only to record events over a considerable period of time, but also to store, for example, control parameters inside the computer and to 'download' this at will to the controllers. This would enable, for example, a large suite of test programs to be stored on a disc and these to be transferred as required to any of a number of furnaces in a particular installation.

It is possible also to use a supervisory computer as an 'on-line' device, that is, to be constantly monitoring the test equipment and to be programmed to make adjustments to it in response to changes. A typical example might be the adjustment of the set point of a creep furnace controller in the event of the sample rupturing.

The networking of computers to each other and/or to a mainframe computer further increases the flexibility of an installation, enabling, for example, access to a complete system from any one of a number of locations in a laboratory.

7.4 Shut-down on mains failure, specimen failure or over-temperature events

For normal mechanical testing of metallic specimens, neither the specimens nor the grips are damaged by rapid temperature changes. With ceramic specimens this is not necessarily so, and the situation can be compounded by two factors. Often the 'grips' or bend test jigs are ceramic, and considerably larger than the specimens, so that the ability of the unit to withstand thermal shock is limited by these components. Also for some types of testing, small furnaces are used with water cooled cases. The natural cooling rate of these small furnaces when the power is switched off can be very fast, and sufficient to damage ceramic components. Under these conditions, a situation can arise when mains failure is potentially as dangerous as a temperature overshoot so far as the integrity of the testing set-up is concerned. Hence, it may be necessary to ensure that stand-by power supplies are available in the event of mains failure: generally a few seconds interruption does not damage, and since brief temporary mains interruptions are more likely than longer-term interruptions, it is desirable to use circuits where mains interruptions of up to say 30 seconds duration do not trip the power.

When temperature overshoot arises conventionally, it is usual to trip power to the furnace. When testing ceramics, the arrangement should ideally be to programme the temperature downwards. However, a temperature overshoot-trip means that either the control unit or the thermocouple has failed and hence cannot be used to programme the temperature downwards. Under these conditions, it may be desirable to use control gear in which the conventional on/off controller that is used as a temperature overshoot-trip is changed for a programme controller in which a suitable cooling programme has been inserted.

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