Temperature measurement —

Part 7: Guide to selection and use of temperature/time indicators

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Committees responsible for this British Standard

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Contents

Foreword

This Part of BS 1041 has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee. It is a revision of BS 1041-7:1964 which is withdrawn.

It is Part 7 of the standard and it differs somewhat from the other four specialist parts which deal with specific types of temperature measuring equipment, in that the devices considered herein are used primarily to indicate the effect of temperature and time by purely comparative means, as opposed to instruments which give a direct reading or recording of the temperature conditions. In the ceramic industry the effect of temperature-time treatment is generally referred to as "heat work".

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Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 12, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This Part of BS 1041 provides guidance on "change of state" devices used to indicate the amount of heat work which the subject being considered has undergone. The two groups of change of state devices which are included are those which change shape or size and those which change colour.

Included in the former are the following:

a) pyrometric cones;

b) thermoscope bars;

c) Bullers rings.

Of the preceding, a) and b) change their shape during heating and c) change size.

The change of colour devices are:

1) temperature indicating paints;

2) reversible colour change indicators and paints;

3) temperature indicating labels.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 1041 the following definitions apply.

2.1
heat work

a qualitative indication of the effect of heat treatment, increasing with temperature and time spent at temperature

NOTE It is used especially in the firing of ceramics.

2.2
pyrometric cone

a slender truncated trihedral pyramid of pressed ceramic material that deforms under particular temperature/time treatment

2.3
touch-down temperature (end-point)

the temperature at which a pyrometric cone will bend so that the tip touches the stand or plaque when heated at a specified rate of temperature rise

2.4
signal cone

in a series of pyrometric cones, the cone that deforms after the least heat work

2.5
indicator cone

in a series of pyrometric cones, the cone whose tip touches the stand when the desired heat work has been applied

2.6
witness cone

in a series of pyrometric cones, the cone that begins to deform next after the indicator cone

2.7
thermoscope bar

a pressed ceramic bar that, when supported at each end in a horizontal position, deforms under its own weight under specified temperature/time treatment

2.8
bullers ring

an annular ring of pressed ceramic powder that contracts with heat work

2.9
temperature indicating paint

paint that undergoes a change in colour after exposure to a specified temperature for a specified time

2.10
single-change paint

a temperature indicating paint that undergoes only one principal colour change under temperature/time exposure

2.11
multi-change paint

a temperature indicating paint that undergoes several colour changes after various specified temperature/time exposures

2.12
signal colour

the colour which a temperature indicating paint turns after the specified temperature/time exposure

2.13
trigger temperature

the temperature at which a temperature indicating paint changes colour at a particular exposure time

2.14
cut-off temperature

the temperature below which a temperature indicating paint exhibits no colour change, no matter how long the exposure

2.15
reversible colour-change indicators

indicators that revert to the original colour on cooling below the colour-change temperature

2.16
temperature indicating label

an adhesive label containing a patch whose colour changes when the surface to which it is attached reaches a specified temperature

NOTE One label may contain several patches to indicate the attainment of a range of temperatures.

Section 2. Indicators that change shape or size

3 General

The temperature/time indicators that depend on the change of shape or size are largely used in the firing of ceramic wares such as grinding wheels, bricks, refractories, electrical porcelain, china, earthenware, sanitary ware, or tiles. These indicators can only be said to measure temperature/time treatment if they are used under the same conditions which existed when indicators of the same specification were compared with a temperature measuring instrument.

Such an indicator does not replace a temperature measuring instrument but is used in conjunction with it; the instrument will indicate the temperature-time treatment at a particular spot in a kiln during a firing cycle, whereas a number of suitably positioned indicators can give a measure of the variation in thermal conditions within a kiln setting.

Pyrometric cones and thermoscope bars are prepared from complex mixes containing various proportions of frits, fluxes, clays, calcium and magnesium compounds, silica, etc., designed to melt or soften within certain temperature ranges that depend on the rates of heating used. Cones deform and slump fairly sharply at a certain stage in the heating cycle. Bars, which are supported at their ends, bend in the middle.

Bullers rings are prepared from clays, fluxes, and inert materials, and do not melt or deform but shrink progressively during a heating cycle; the effect of temperature and time (heat work) is assessed by measuring the shrinkage of the indicator.

4 Pyrometric cones

4.1 General

Cones are manufactured in two sizes, the normal or standard cone with a height of about 60 mm, and the laboratory cone with a height of about 30 mm. Both can be used to monitor and control industrial kilns, but small cones are specified for determining the refractoriness of raw materials in accordance with BS 1902-5.2, ISO 528, and DIN 51063-1 and DIN 51063-2.

Cones from different sources vary in shape, manner of usage, and performance.

4.2 Characteristics

4.2.1 *Construction*. Pyrometric cones (see Figure 1) are typically slender truncated trihedral pyramids about 30 mm or 60 mm in height.

4.2.2 *Cone numbers*. Pyrometric cones are traditionally numbered from 022 to 20; this method of numbering has a historical basis, following original Seger practice, which is broadly accepted by other manufacturers. Temperature steps of 15 °C up to 30 °C exist between each cone number, and 42 cones cover the temperature range 600 °C to 1 535 °C (see Table 1).

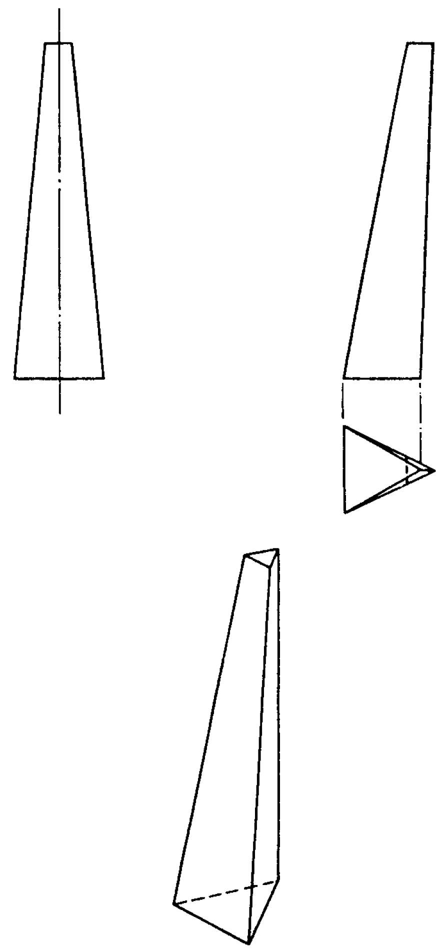

Figure 1 — Form of pyrometric cones

4.2.3 *Touch-down temperature*. This is the temperature at which a cone set up in the correct manner (see **4.3.1**) will bend and touch the stand when heated in a kiln at a specified rate of rise of temperature.

A heating rate of 60 °C/h was used in preparing Table 1. Faster rates of heating will raise the touch-down temperature and vice-versa.

Laboratory cones, because of their lower mass, and because they are subjected to faster heating rates, usually fall at higher temperatures than normal cones of the same number and composition.

NOTE Though the temperatures in Table 1 may correspond approximately to those in tables provided by overseas cone manufacturers, cones of the same number from different producers should not be regarded as interchangeable.

Table 1 — Approximate touch-down temperatures of pyrometric cones

Cone no.	Temperature	Cone no.	Temperature	Cone no.	Temperature
	°C		°C		°C
022	600	08	950	7	1 230
021	615	07	975	8	1 250
020	630	06	1 000	9	1 270
019	665	05	1 030	10	1 290
018	700	04	1 060	11	1 310
017	730	03	1 085	12	1 330
016	760	02	1 105	13	1 350
015	790	01	1 120	14	1 380
014	810	1	1 135	15	1 410
013	830	2	1 150	16	1 435
012	860	3	1 165	17	1 460
011	880	4	1 180	18	1 485
010	900	5	1 195	19	1 510
09	925	6	1 210	20	1 535

NOTE 1 Each temperature given in the table is that at which the tip of a cone will bend sufficiently to touch the base, in an electric kiln with a heating rate of 60 °C/h.

NOTE 2 The touch-down temperature depends on the rate of heating; reports on firing behaviour should quote the cone number, not the temperature taken from the above table.

NOTE 3 Intermediate degrees of bending can be referred to the hands of a clock, e.g. 3 o'clock would represent a cone bent halfway to the stand.

4.3 Method of operation

4.3.1 *General*. The method described in **4.3.2** to **4.3.5** can be generally applied under most firing conditions for which cones are suitable.

4.3.2 *Setting up*. While single cones are sometimes used it is recommended that three or four consecutively numbered cones are inserted into specially made unfired plaques which hold the cones at the correct angle to the vertical. These plaques have tapered holes and protrusions on one or more internal faces so that the cone is firmly held; during firing, plaque and cone contract similarly so that the cone is held firmly throughout the firing. A cone may be set up in other ways, such as inserting its base into refractory clay, but the importance of maintaining a correct angle and a firm hold at all times cannot be over-stressed. Failure in these respects will cause the cone to bend unpredictably, and to give an incorrect assessment of the heat treatment.

NOTE Cones from different sources differ in shape, size, and the manner in which they are set up before firing. Each producer's instructions should therefore be studied carefully and strictly adhered to if satisfactory performance during firing is to be obtained. Some manufacturers make cones with thickened bases which do not require stands.

4.3.3 *Choice of cones*. The range of the three or four cones chosen should extend above and below that of the cone expected to indicate the desired heat treatment.

4.3.4 *Usage in kilns*. Since the temperature throughout a kiln is rarely uniform several plaques of cones can be placed in different parts of the kiln, so that an estimate of the variation in heat work from place to place can be obtained.

4.3.5 *Behaviour during firing*. As the firing cycle progresses and the heat work approaches that at which the signal cone is affected, the cone will begin to soften and bend, and will continue to bend until the tip just touches the plaque on which the cone has been placed. This is considered to be the end-point of the cone. With further prolongation of the firing cycle, with soaking or increase in temperature, the cone will melt completely to form a blob on the plaque. The next cone of the series will begin to deform some time after the first started to bend and will continue to bend until its end-point is reached. The appropriate level of heat work will have been reached when the indicator cone has just reached its end-point. Under these firing conditions the witness cone will be only partially bent over.

4.4 Operating features of cones

4.4.1 *General*. Cones containing frits giving relatively low viscosity glasses are appropriate for low temperatures (e.g. less than 1 200 °C) whereas mixtures of minerals reacting and melting to produce more viscous glasses are used for higher temperatures. Since cones consist partly of glass or glass-formers plus more refractory clays and silica it follows that cones do not have definite melting points; they deform only when the decreasing viscosity of the liquid phase permits movement under the influence of gravity. The performance of cones is largely controlled by temperature, but time (e.g. rate of heating, soaking at a given temperature) and kiln atmosphere are also significant.

Enamels and glazes fired at the lower temperatures contain proportions of frit as do the cones. Many ceramic products are based on mixtures of silicate minerals as are the cones for higher temperatures. Because temperature and time affect ware and cones similarly, cones are useful for controlling the progress of firing of many ceramic products. The touch-down of a cone can indicate the point at which ware will mature under a controlled rate of heating and a particular set of atmospheric conditions, which should then be maintained. If such conditions do not alter, the cone will always touch-down at the same temperature.

4.4.2 *Burnout of binder*. As cones contain an organic binder, heating rates in the low temperature region should be slow enough to ensure that the binding material is completely burned out, as residual binder can prevent satisfactory behaviour of the cone later, and even cause swelling and instability.

4.4.3 *Rate of heating*. The viscosity of the molten glass decreases sharply with temperature, and reaction rates between glass-producing minerals approximately double with every increase of 10 °C; the touch-down temperature of a cone is therefore dependent on the rate at which the temperature has increased. The rate of heating is less important in the earlier stages of firing as long as glasses have not melted or liquid-forming reactions commenced. However as soon as these processes begin to operate the rate of heating becomes significant. In general the slower the rate of heating the lower will be the temperature at which deformation proceeds.

With cones heated at 20 °C/h and 150 °C/h, differences in end-points of as much as 60 °C have been recorded. The trend to very fast firing of certain ceramic products raises the end-point of a cone still further.

NOTE Some manufacturers of cones provide tables showing the touch-down temperatures of cones at various rates of heating.

4.4.4 *Kiln atmosphere*. In practice cones should be protected from direct contact with flames and from draughts of cold air. The effect of atmosphere depends to some extent on the composition of the cone, e.g. those containing iron oxide (red cones) can be reduced. British pyrometric cones do not contain added iron oxide and are relatively insensitive to reducing conditions.

Direct exposure to flames or to dissociated hydrocarbons in the early stages of firing may deposit graphitic carbon in surface pores or leave a hard crust of carbon: this fails to melt so that the outer portion of the cone remains as an erect shell, even after the centre has softened and flowed out at the base.

Sulphurous gases can also create shells in bad cases; these gases can also raise the viscosity of molten silicate glasses, e.g. the end-point of some cones when used in an atmosphere containing 0.35 % sulphur dioxide can be raised as much as 35 °C.

5 Thermoscope bars

5.1 Construction

Thermoscope bars contain a range of frits, clays, feldspars, silica, and other minerals, similar to those used in pyrometric cones. Compositions, as with cones, are varied to produce bars which bend at different temperatures. The bars are made by dust-pressing, with an organic binder, and are typically about 57 mm × 8 mm × 6 mm. Though normally used in the as-pressed state, bars can be hardened in manufacture, by pre-firing at a suitable temperature below that at which bending should occur.

5.2 Bar numbers

Table 2 lists the approximate bending temperatures for a range of 42 bars, giving an operating range from 590 °C to 1 525 °C. Intervals between bars vary from 15 °C to 30 °C.

Table 2 — Approximate bending temperatures of thermoscope bars

Bar no.	Temperature	Bar no.	Temperature	Bar no.	Temperature
	°C		°C		°C
1	590	15	940	29	1 220
2	610	16	965	30	1 240
3	625	17	990	31	1 260
4	650	18	1 015	32	1 280
5	685	19	1 045	33	1 300
6	715	20	1 075	34	1 320
7	745	21	1 095	35	1 340
8	775	22	1 115	36	1 365
9	800	23	1 130	37	1 395
10	820	24	1 145	38	1 425
11	845	25	1 160	39	1 450
12	870	26	1 175	40	1 475
13	890	27	1 190	41	1 500
14	915	28	1 205	42	1 525

NOTE 1 Each temperature given in the table is that at which the bar starts to bend in an electric kiln with a heating rate of 60 °C/h.

NOTE 2 The bending temperature depends on the rate of heating; reports on firing behaviour should quote the bar number, not the temperature taken from the table.

NOTE 3 The bar can be expected to bend sufficiently to touch the stand at a temperature of 10 °C to 30 °C higher than the values given in the table, depending on the composition of the bar.

5.3 Operation

Up to four consecutively numbered bars are placed horizontally on a refractory stand (preferably stepped), so that they are about 12 mm apart and supported only at their ends (see Figure 2).

When subjected to an increasing temperature, eventually the lowest numbered bar will begin to bend; the degree of bending continuously increases with rising temperature until the bar contacts the base of the stand and finally fuses. As the heat work approaches that which the selected bar is to indicate, this bar will have just begun to bend, while the higher numbered bars remain unaffected.

The use of an alumina-china clay wash on the refractory stand will help release of the fired bars, so that the stand can be reused.

5.4 Operating features

As cones and bars are manufactured from very similar materials all the effects of heating rate, soak, and atmosphere described for cones are applicable to thermoscope bars.

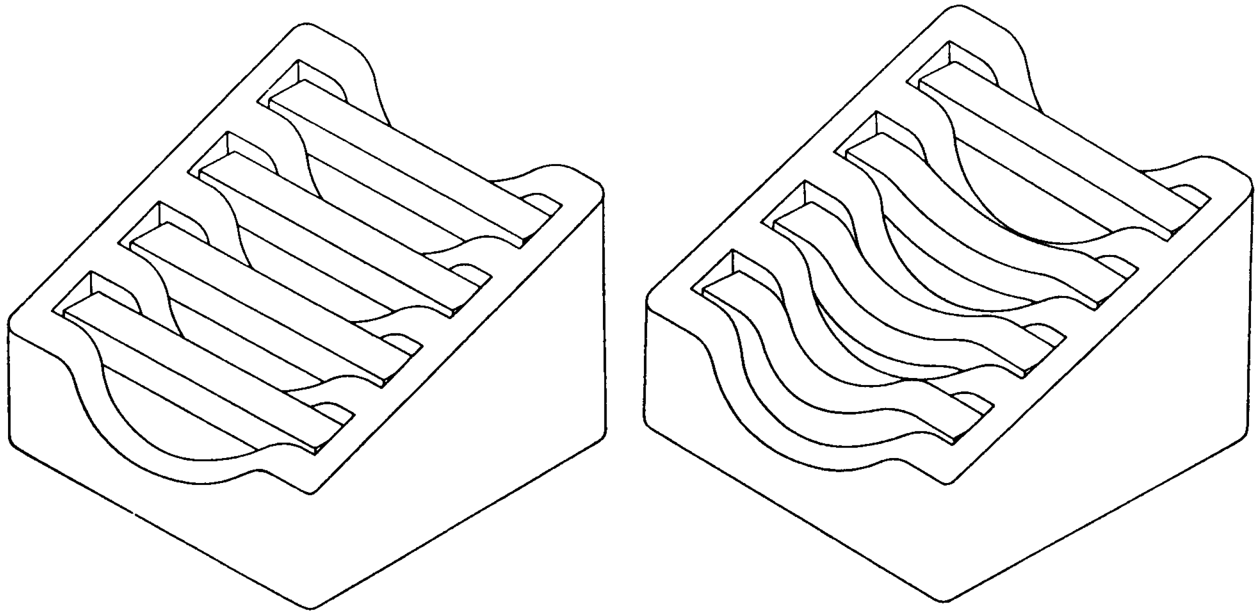

Figure 2 — Thermoscope bars on stand before and after firing

6 Bullers rings

6.1 General

In contrast to cones and bars, Bullers rings give no immediate visible indication that a certain level of heat work has been reached. Instead, the contraction of the ring, which occurs on firing and which indicates the heat work, is measured on a gauge.

6.2 Characteristics

6.2.1 *Construction*. A Bullers ring (see Figure 3) consists of an annular ring of rectangular cross section made of pressed, unfired ceramic material. It is approximately 63 mm diameter and 8 mm thick with a centre hole of 22 mm diameter. The ring is made from material which contracts fairly uniformly with increase of temperature throughout the operating range.

6.2.2 *Operating range*. The temperature range covered by Bullers rings is approximately 960 °C to 1 400 °C as shown in Table 3, this overall range being covered by materials of four different compositions each suitable for different groups of products as follows.

a) *Number 55 rings (coloured brown)*. These rings, whose range is 960 °C to 1 100 °C, have a rapid shrinkage above 1 000 °C and are used in the firing of glost ware and common building bricks where the finishing temperature is rather low.

b) *Number 27/84 rings (coloured green)*. Recommended over the temperature range of 960 °C to 1 250 °C when firing earthenware and tiles, building bricks, engineering bricks and fire bricks.

c) *Number 75/84 rings (coloured natural)*. Recommended for firing temperatures from 960 °C to 1 320 °C. These rings can be satisfactorily used wherever the number 27/84 rings are suitable but have an increased firing range which permits their use at rather higher temperatures. They are chiefly used in the firing of electrical porcelain, china biscuit, grinding wheels, fire bricks and refractories.

d) *Number 73 rings (coloured yellow)*. Recommended for temperatures from 1 280 °C to 1 440 °C, especially in slow firing conditions as is customary with higher grade fire bricks and heavy refractories.

6.3 Method of operation

6.3.1 Several rings of the same composition are placed vertically in a prefired stand; several stands are located in the kiln in such a manner that individual rings can easily be withdrawn. Alternatively rings can be placed on any horizontal surface and not removed until the firing has been completed. In continuous car tunnel kilns, rings may be placed where convenient and withdrawn at suitable points along the tunnel up to and including the firing zone.

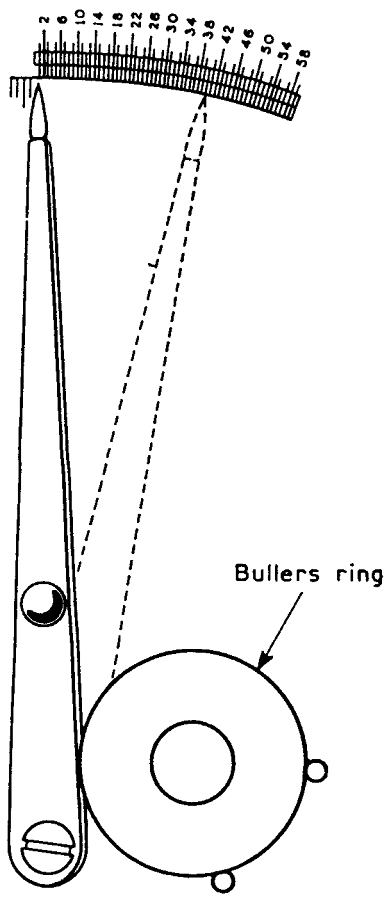

Figure 3 — Bullers ring and gauge

6.3.2 At various times, as firing progresses, a ring is withdrawn from each stand, cooled and measured (see **6.3.3**) so as to determine:

a) the uniformity of heating throughout the kiln;

b) whether the firing is progressing favourably;

c) when the kiln has been fired sufficiently.

Firing is complete when rings of certain contractions have been obtained in various parts of the kiln, as determined (for the particular ware) by previous experience.

6.3.3 Measurement of the contraction, and therefore the heat work indicated by the rings, is carried out on a gauge consisting of a brass base plate on which are mounted a radial arm with pointer moving over a scale and two steel dowel pins against which the ring is pressed by the movable arm when measurements of pointer number are being taken (see Figure 3). A contraction of the ring gives rise to an amplified movement of the pointer over the scale. The scale is engraved on the brass plate and is so numbered that the higher fired rings, which have contracted more, give a higher reading on the gauge. The divisions on the scale are numbered 0 to 60 above and 0 to 5 below the zero mark, the latter readings indicating expansion and the former contraction.

NOTE On being heated the rings first expand slightly then return to their initial size when a temperature of approximately 960 °C is attained and subsequently contract gradually to an extent which depends on the heat treatment received.

Rings should be measured across several diameters, by turning them round in the gauge, and the mean value given to the nearest half pointer number.

A necessary precaution with the gauge is to see that the bearing on which the pointer works and the two pins and side of the pointer against which the ring rests when being measured, are not worn. In the course of time these are liable to wear and an error of one or two divisions on the scale can be obtained. Allowance should be made for this by checking from time to time against a "control ring" which may be of metal. When the wear is pronounced the gauge should be replaced or repaired.

6.4 Operating features

Since the rings themselves, throughout their operating range, consist largely of non-fusible ceramic material they form the most truly comparative means of heat work measurement for ceramic ware. Variations in the rate of heating would generally affect the ware in the same way as the rings.

6.5 The effect of firing rate and soak on the behaviour of Bullers rings

Users of Bullers rings are always advised that the ring values given in the temperature chart should be used with caution because they are dependent on the firing cycle to which the rings are subjected.

With the introduction of rapid firing for certain types of ceramics this cautionary advice has become more significant. However, in some branches of the industry temperatures may be held for long periods to ensure that thick sections are correctly fired. Ring values can be altered very considerably at these two extremes of firing and some measure of these differences has been determined experimentally.

It is probable that the rate of heating up to 950 °C has a negligible effect on ring behaviour. In laboratory trials rings were heated to a given temperature and rings were withdrawn at 0, 1, 2, 4, 8, 16, 32, 64 h intervals and their values recorded. When plotted it was seen that most of the contraction of the rings occurred in the early part of the "soak" period, and that rings reached near-stable values with a prolonged soak.

Table 3 — Approximate temperature chart for Bullers rings

Temperature	Ring no. 55 (brown)	Ring no. 27/84 (green)	Ring no. 75/84 (natural)	Ring no. 73 (yellow)
	Gauge reading			
°C				
960	3	0	0	
970	7	1	1	
980	11	2½	2	
990	15	4	3	
1 000	18	5½	4	
1 010	21	7	5	
1 020	24	8½	6	
1 030	27	10	7	
1 040	30	11½	8½	
1 050	32	13	10	
1 060	34	14	11	
1 070	36	15½	12½	
1 080	37	17	14	
1 090	38	18½	15½	
1 100	39	20	17	
1 110		21½	18	
1 120		23	20	
1 130		24½	21	
1 140		26	22	
1 150		27	23	
1 160		28½	24½	
1 170		30	26	
1 180		31½	27	
1 190		33	28	
1 200		34½	29	
1 210		36	30	
1 220		37½	31	
1 230		38½	32	
1 240		40	33	
1 250		41½	34½	
1 260			36½	
1 270			38½	
1 280			40	29½
1 290			42	30
1 300			44	31
1 320			46	34
1 340				37
1 360				40½
1 380				44
1 400				48
1 420				51
1 440				54

NOTE These values should be used with caution because they are dependent on the firing cycle to which the rings are subjected.

Section 3. Colour-change indicators

7 General

Colour-change indicators comprise paints or labels which undergo colour changes at specific temperatures, either reversibly or irreversibly. For some substances several distinct colour changes may occur. These changes provide a visual indication or record of temperature exposure, and since in most cases the time of exposure is an important parameter, they fall naturally into this Part of BS 1041.

The measurement of the temperatures of surfaces using thermocouples is often problematical because good contact has to be established, without at the same time altering the temperature of the surface to be measured. Radiation pyrometers operate without contact and can possess good sensitivity even at moderate temperatures, but the accuracy of the measurement depends substantially on a knowledge of the emissivity of the target surface. In these circumstances the application of a paint or a label to a surface to obtain an indication of temperature exposure can be extremely convenient. It offers the advantage of simplicity and flexibility, and can also achieve useful reliability and accuracy.

8 Temperature indicating paints

8.1 General

Temperature indicating paints incorporate thermally sensitive pigments which change colour when exposed to heat. The colour change in indicators is the result of chemical change and is irreversible. The paint provides a clear visual record that a certain temperature exposure has been exceeded. Colours before and after heating are quite distinct and the change is easily recognizable. As the paint is in intimate contact with the surface under examination, temperature variations over areas of any dimension can be recorded. The paints can be directly applied at room temperature, by brush or spray, to practically any surface. In order to obtain the most accurate and clear indication of transition temperature, the paint should be applied so as to give as complete and even a coverage as is possible.

8.2 Composition and characteristics

Temperature indicating paints are basically acrylic lacquers containing finely dispersed temperature-sensitive inorganic pigments. The pigments used in each type of paint are specific for the transition temperature required. These pigments, once heated above a particular level, will undergo chemical change which is seen as a change in colour.

The fact that heat causes a gradual transition in the molecular structure of the sensitive particles means that the change is less rapid than that which occurs with a melting-point material. There is therefore a time factor to be considered when assessing the temperature of a colour transition. However, when the temperature is below a certain level, known as the cut-off temperature, this level being different for each paint, then no colour change takes place, no matter how long the paint is heated.

Paints can be divided into two groups. Single-change paints undergo one reliable colour change in the range 60 °C to 610 °C. Multi-change paints change through a spectrum of colours at various points in the range 150 °C to 1 100 °C.

Up to 235 °C single-change paints are available in a "two-pack" form. The pigment is dispersed in an hydroxy-functional acrylated resin, and just prior to application a second resin, a cyanide copolymer, is added. The chemical reaction of the polymerization between the resins provides a tough and weather-resistant finish.

Manufacturers prepare batch calibration curves showing the temperature/time relationships which, for appropriately formulated paints, are reliable and repeatable. Experienced operators using the manufacturer's calibration curves should obtain results accurate within 5 % of the Celsius temperature. The most accurate measurement will be made if the conditions of use exactly correspond to the calibration conditions so far as heating and cooling times, temperatures and atmospheric conditions are concerned.

8.3 Applications

When a body undergoes a rise in temperature it is usual for a temperature gradient to appear across the surface. This lack of uniformity can be efficiently demonstrated by the use of temperature indicating paints. When any point on the surface reaches a temperature in excess of the transition value for the paint in use, a colour change will take place. This will leave part of the area in the original colour and part in the new colour, the two hues being, as it were, bounded by an isothermal line, i.e. all points along this line were, at the time of transition, at the same temperature. When a multi-change paint is used, a number of bands of colour will appear successively as the temperature rises. The colour change of temperature indicating paints is caused by physical or chemical alterations in the pigments. In most cases molecules of water, carbon dioxide, etc., are lost, resulting in a change of hue, and it is these colour changes which enable a permanent thermal record to be made of the temperature gradient across a surface.

The many industrial uses of temperature-sensitive paints fall into two categories. First they may be used purely to observe heat patterns, so enabling high or low temperature points to be detected. This is particularly important at very high temperatures when the effect of cooling gases may be upset by rivet heads, etc. This would cause gas to be locally diverted from the surface, and so give rise to an abnormally high surface temperature. Both the efficiency of insulation and the uniformity of heat dispersion can be studied using paints.

The second way in which thermal paints are used is in the measurement of temperature. This can be done on any surface no matter if it is inaccessible or revolving at high velocity during the thermal examination. To make such measurements it is essential to have calibration graphs to relate the colour to the time/temperature cycle.

The composition of multi-change paints allows them to perform in hostile gases. Some paints have good surface adhesion at high temperatures, and so are an invaluable asset in gas turbine and jet engine diagnostics.

For the selection of the most suitable paint for a particular application, reference should be made to calibration graphs, the estimated surface temperature, and the trigger temperature required.

8.4 Assessment of paint characteristics

Thermal paints can be conveniently assessed on a low-voltage resistive test rig, using a butterfly-shaped metal (nimonic or similar) plate as the test surface. The construction of the butterfly offers a non-uniform resistance per unit length, thus producing temperature gradients during the passage of an electric current. The heating current is regulated using thermocouples tack-welded to the test plate near the constriction. Thermocouples are also attached to the ends of the plate to measure the "soak" temperature.

When a paint is to be checked, a uniform coat is applied and allowed to dry. The control and soak thermocouples are then attached, and the rig control set to the desired temperature for a selected heating period, typically 10 min. After this time the soak temperature is measured, and the rig is switched off.

A new thermocouple is now attached to the isothermal line at the boundary of the colour change of the paint. The rig is then reheated for another 10 min period, with the control unit setting unaltered from the first run. The soak thermocouples are then read and the temperature at the colour change thermocouple is recorded. Having thus established the temperature at which the paint changes colour, the rig is switched off and the control unit is connected to the thermocouples which were used to measure the isothermal line. The plate is then repainted and the rig run for 10 min with the control unit set at the measured change temperature. If the reading is correct, the new isothermal line of colour change crosses this thermocouple after 10 min heating.

Using this system all time/temperature readings can be measured and checked. Time/temperature graphs of up to 50 h duration are customarily produced for each paint.

Table 4 and Table 5 show the transition temperatures for a number of single- and multi-change paints when heated at a constant temperature for a period of 10 min. Figure 4 and Figure 5 show that the transition temperatures initially decrease rapidly with increasing exposure time, but that the curves level off at longer heating periods. After 5 h or so any further decrease is small in most cases.

9 Reversible colour-change indicators and paints

9.1 General

Reversible colour-change indicators are invaluable when it is necessary to detect undesirable temperature excursions, correct faults and revert to normal conditions. They are widely used in the electrical industry, especially on busbars, live conductors and connectors in high current switches, and in electronic fault-finding. They are also used as warning and indicating devices in both the domestic and industrial environments, for example in place of neon indicators in domestic appliances.

9.2 Characteristics

Reversible temperature indicators are available as paints and in label form. Paints are available that give strong colour changes at various temperatures up to 170 °C. At the lower temperatures the thermal pigments are mercury-based complexes which cannot be applied directly to metal surfaces as this causes decomposition. They also tend to decompose after long exposure to heat, but the decomposition can be retarded by using a clear over-lacquer. These pigments find their most successful application when encapsulated into labels.

9.3 Repeatability and testing

For temperatures up to 70 °C under test conditions a repeatability of indication of ± 1 °C can be achieved. For temperatures up to 150 °C this increases to ± 2 °C and from 150 °C to 170 °C it increases to ± 3 °C. Ageing effects are small.

Paints and labels of this type have been shown to be durable and to withstand sunlight and adverse weather conditions for a projected life of 2 years.

9.4 Liquid crystal indicators

A liquid crystal, as the name implies, is a chemical which is both liquid and crystalline, possessing some of the mechanical properties of a liquid and the optical qualities of a crystal. Several different types of liquid crystal have been discovered, some of which are widely used in electronic displays.

Certain liquid crystals are thermochromic; that is, they change colour with temperature. The structure of these crystals is such as to selectively reflect light of a narrow waveband whilst transmitting light outside this band. If the transmitted light is finally absorbed into a dark background, only the reflected wavelengths are seen, as a pure iridescent colour. Typically, as the temperature increases the wavelength of the reflected light decreases. A liquid crystal on warming will first show a red colour, then go through the spectrum to green, blue and violet, ending up in the ultraviolet, at which point only the black background is seen. Thus the colour is an indication of temperature, and the span over which the changes occur can be 0.5 °C to 20 °C wide.

Among materials used, cholesteric esters operate in the range from – 2 °C to + 44 °C, typically with a resolution of ± 1 °C. These compounds are not very stable, however. Other materials, such as chiral nematics, which are more stable, offer greater resistance to ultraviolet light, and are usable within the approximate range – 30 °C to + 150 °C.

In the form of adhesive labels, they can be used for a variety of applications where continuous display is required. Non-adhesive labels are especially adapted to clinical use, in the measurement of skin temperature. However, the relatively high expansivity of the crystals limits the long-term use of such labels, at least when large temperature excursions are involved.

Table 4 — Examples of single-change paints

Original colour	Signal colour	Initial trigger temperature[a]	Cut-off temperature
		°C	°C
pink	blue	48	30
pink	blue	135	110
mauve pink	blue	148	120
blue	dark green	155	46
yellow	red	235	180
blue	fawn	275	150
mauve red	grey	350	220
mauve	white	386	290
green	salmon pink	447	312
green	white	458	312
orange	yellow	555	482
red	white	630	450

[a] Colour-change temperature for 10 min heating.

Table 5 — Examples of multi-change paints

Original colour	Signal colour	Initial trigger temperature[a]	Cut-off temperature
		°C	°C
light tan	bronze green	160	150
bronze green	pale indian red	230	210
reddish orange	dark grey	242	193
dark grey	medium grey	255	211
medium grey	dirty white	338	228
purple	pink	395	355
pink	fawn	500	386
fawn	blue	580	408
red	dusty grey	420	310
dusty grey	yellow	555	328
yellow	orange	610	450
orange	green	690	535
green	brown	820	621
brown	green/grey	1 050	945

[a] Colour-change temperature for 10 min heating.

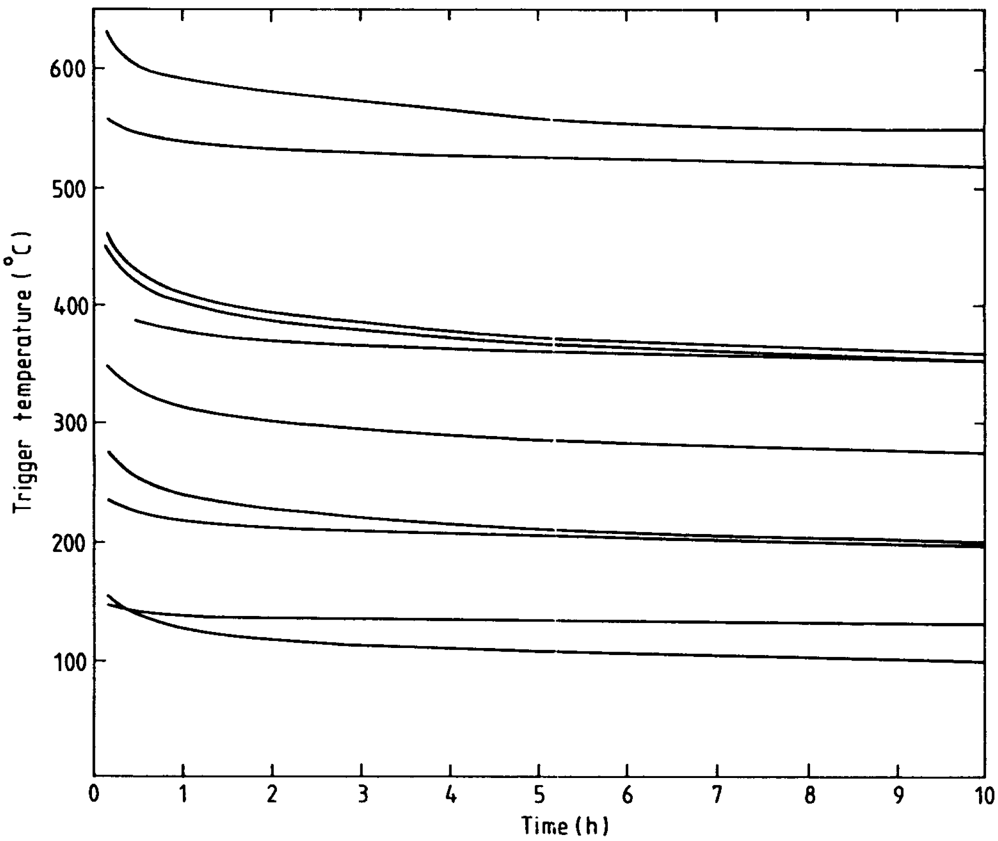

Figure 4 — Examples of trigger temperature-time relationships for some single-change paints

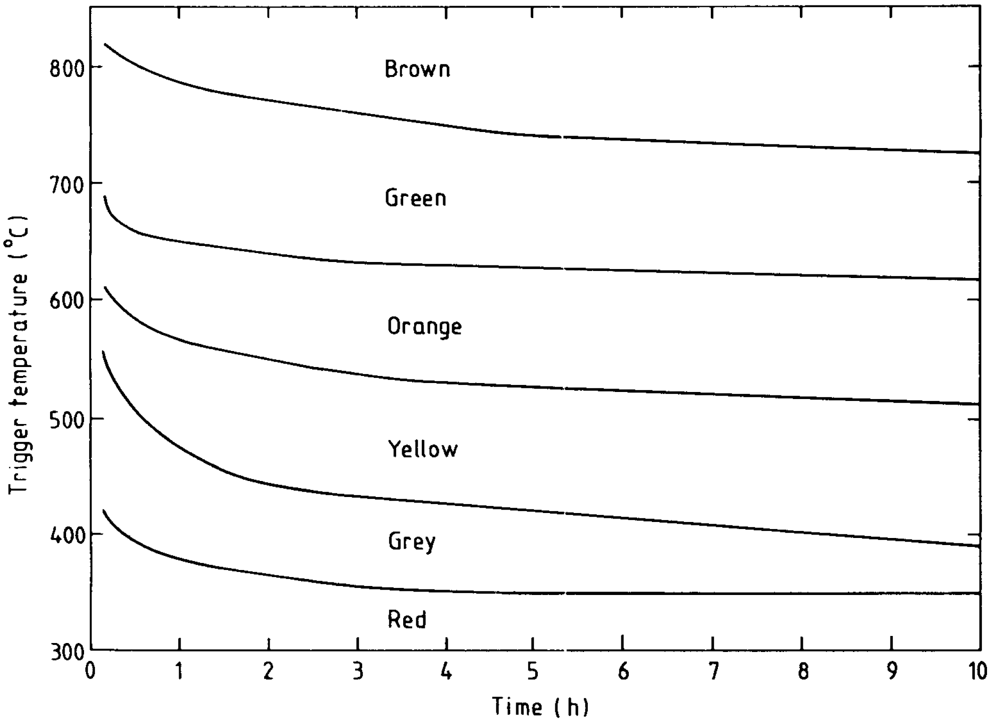

Figure 5 — Examples of trigger temperature-time relationships for a multi-change paint

10 Temperature indicating labels

10.1 General

Most temperature indicating labels, unlike those discussed in clause **9**, rely on the melting of a white chemical coating to reveal a black paper backing. As the melted chemical is absorbed by the paper, the colour change is irreversible.

The chemically coated paper is protected by encapsulation under a polyester film. The labels are self-adhesive and, once applied to a clean surface, are water and oil resistant. Such indicators are produced in various forms, depending on the application. Often several labels are assembled in a strip to give the appearance of a thermometer, although the indication changes only at successive "trigger" points.

10.2 Characteristics

Many labels are presently available, giving colour changes within the range from 30 °C to 300 °C. The chemicals are stable on heating up to the trigger melt-point, and unlike the paints described in clause **8**, no change takes place until the trigger temperature has been reached. Also they are not appreciably time sensitive.

Thermal papers are stable and effective and can be made to give indications under test conditions with a tolerance of ± 1 °C up to 100 °C and ± 1 % at higher temperatures.

Publications referred to

BS 1902, *Methods of testing refractory materials*.

BS 1902-5.2, *Determination of pyrometric cone equivalent (refractoriness) (method 1902-502)*.

ISO 528, *Refractory products — Determination of pyrometric cone equivalent (refractoriness)*.

DIN 51063-1, *Testing of ceramic raw and finished materials: Pyrometric cone of Seger (SK): Determination of bending point (pyrometric cone equivalent)*.

DIN 51063-2, *Testing of ceramic materials: Pyrometric reference of Seger (SK): Testing of Seger cones*.

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