A Thermocouple for High Temperatures

ADVANTAGES OF THE 'FIVE-TWENTY' COUPLE

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For a great many years the thermocouple formed by connecting pure platinum to the alloy of platinum with 13 per cent of rhodium has been the most widely used of all noble metal couples. The reliability of this couple is such that it has been adopted as the standard by which temperatures between 660° C and the melting point of gold (1063° C) are established on the International Temperature Scale, and it is of course widely used throughout industry, particularly in determining the temperature of molten steel.

If need be, and if sufficient precautions are taken, this couple can be used to measure temperatures accurately up to just below the melting point of platinum, 1769° C, and indeed it can be calibrated at the melting point of platinum by heating carefully in a gradient furnace until the platinum wire of the couple melts back at the junction.

However, at temperatures over about 1650° C the platinum wire becomes weak mechanically and needs to be carefully supported to avoid creep failure under quite low loads, so that it is not generally practicable to use the couple—even for single-immersions in liquid steel—at temperatures much above 1650° C, and for regular temperature recording or control it is usual conservatively to regard 1500° C or 1550° C as the safe upper limit.

The majority of industrial high temperature operations fall within the range covered by this standard couple, but there is, of course, a small demand—and one which is likely to grow rather than to diminish—for a thermocouple capable of working consistently and satisfactorily at higher temperatures. A great number of thermocouple combinations has been proposed for such applications, but none is entirely satisfactory. Some, such as the tungsten-molybdenum and the tungsten-iridium thermocouples, need to be protected from oxidation and nearly all of them—including the frequently mentioned Feussner couple between iridium and a 40 per cent iridium-rhodium alloy—are either very brittle and difficult to install or tend to embrittle

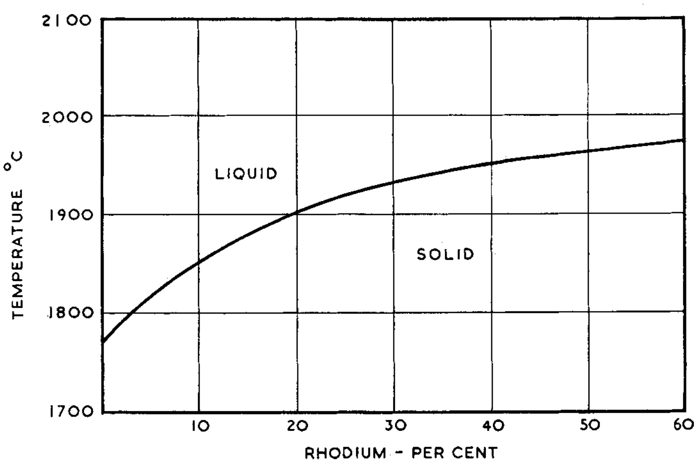


Fig. 1—Liquidus-solidus curve for rhodium-platinum alloys

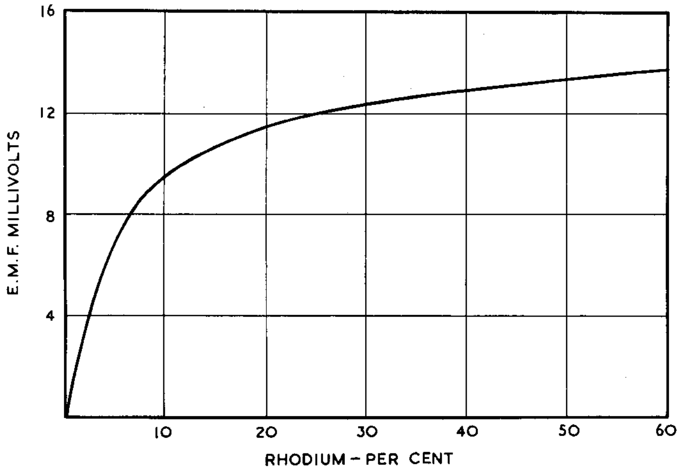


Fig. 2—E.m.f. of rhodium-platinum alloys against platinum at 1000° C

seriously in use. Moreover, many are unstable in service, generate only a very minute e.m.f., or develop inflected e.m.f.-temperature curves.

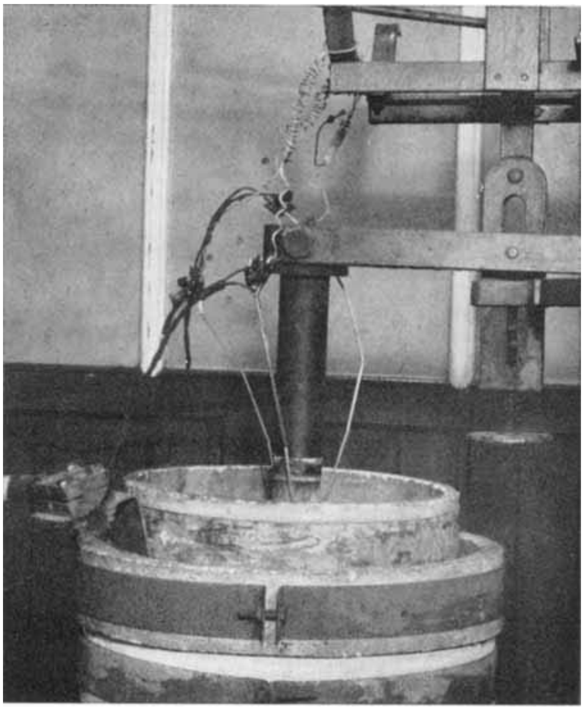
For these reasons, attention has recently been re-directed to the possibility of using two rhodium-platinum alloys as a thermocouple element. The addition of rhodium to platinum is known to raise the solidus temperature, and although the shape of the solidus curve is not well established, it is generally thought to be somewhat as shown in Fig. 1. Thus, by substituting a rhodium-platinum alloy for pure platinum, it is obviously possible to increase the range of temperatures that can be measured before one of the wires starts to melt.

The e.m.f. developed between two rhodium-platinum alloy wires is, of course, less than that between the alloy richest in rhodium and pure platinum. It is, in fact, equal to the difference between the e.m.fs. developed by the two couples, one between the richer alloy and pure platinum and the other between the poorer alloy and pure platinum at any temperature. The e.m.f. developed by any combination at 1000° C can thus readily be derived from Fig. 2.

The problem which thus remains is to choose a couple combination such that:

(1) The melting point of the wire poorer in rhodium should be as high as possible.

(2) The e.m.f. developed at the working temperature should be as high as possible.



The 5 : 20 thermocouple is used in testing refractory bricks under compressive load at high temperatures in the Dorman Long research department

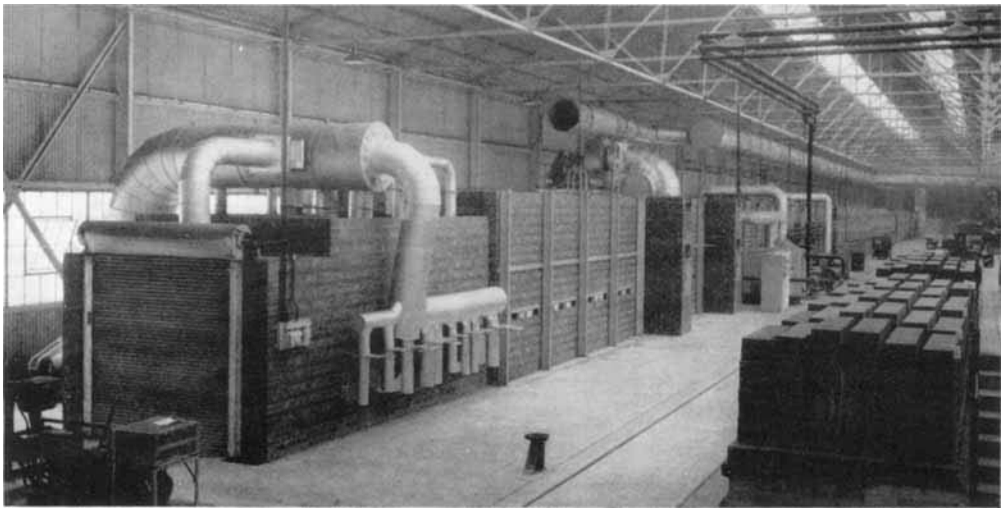
(3) The two wires should be ductile and easy to fabricate and use.

The first condition requires that all wires should be as rich in rhodium as possible, but the third condition limits the composition of the wire richest in rhodium to the alloy containing about 20 per cent.

In order to obtain as high an e.m.f. as possible it seems desirable that the wire poorer in rhodium should not contain much more than 5 per cent of rhodium, although rather more could be tolerated with sensitive measuring instruments. On the whole, however, it would appear that the 5 per cent rhodium : 20 per cent rhodium couple is about the most desirable combination obtainable, and experience with this couple in practice has confirmed its value as a high temperature thermocouple. It can be used continuously at temperatures up to about 1700° C, while its absolute limit for single determinations is set by the melting point of the 5 per cent alloy, which is approximately 1825° C.

The above reasoning, however, is not quite the whole story. The use of 5 per cent rhodium-platinum alloy in place of platinum brings with it three added advantages which are not always appreciated. One is that the alloy addition very greatly increases the strength of the platinum wire at high temperatures and almost entirely eliminates the danger of fracture by creep at temperatures above about 1700° C. Moreover, the couple consisting of two rhodium-platinum alloys is more tolerant of small amounts of contaminating elements in service. It has the added advantage that the room temperature e.m.f. is negligible so that for many purposes a controlled cold junction and special compensating leads need not be used.

All in all, therefore, the 5 per cent rhodium-platinum : 20 per cent rhodium-platinum thermocouple represents a notable advance in the provision of thermocouples suitable for measuring very high temperatures. It has found an increasing use in measuring the temperature of open-hearth furnace roofs, for example, and in the manufacture and testing of refractories. The illustration on page 21 shows a test-rig in the research department of Dorman Long and Co. Ltd. for investigating the behaviour of refractory bricks under compressive load. Formerly this work was carried out with an optical pyrometer, but the use of the 5 : 20 couple has given greater precision in the range 1600 to 1730° C in which failure occurs.



This new tunnel kiln, firing basic refractory bricks at temperatures up to 1650° C at the Worksop plant of General Refractories Ltd., is equipped with 5 : 20 rhodium-platinum thermocouples