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Ceramic Specimen Heating by Induction Power

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1 INTRODUCTION

Induction heating has been used for years as a well-accepted method of heating metallic specimens for mechanical properties testing. Ceramic specimens, on the other hand, are usually heated in a resistance furnace because many ceramic materials cannot be heated inductively. However, indirect heating by induction power can be accomplished for ceramic materials testing using a special technique.

Both heating methods are needed for different reasons such as type of mechanical tests, design of load-train assembly, operating cost, and differences in physical properties of ceramic materials; for example, some ceramics are better thermal conductors than others. Testing ceramic specimens with high thermal conductivity requires special gripping fixtures made of a good thermal insulator with high temperature strength and a high-output resistance furnace to compensate for the heat loss which occurs at both ends of the load-train. Inevitably, the equipment cost will be high.

Specimen heating by induction power is a simple and effective method that is particularly suitable for use in testing ceramics with low thermal conductivity. The advantage of induction heating is that the heat input can be focused on the midsection of the test specimen. This leaves both ends of the specimen to be heated only by conduction, so that high temperature metal alloys can be used for the specimen gripping fixtures which are more economical compared to ceramic gripping fixtures. However, the maximum specimen temperature will be limited by the ability of the metal pull-rods to withstand the load at the maximum service temperature, which is about

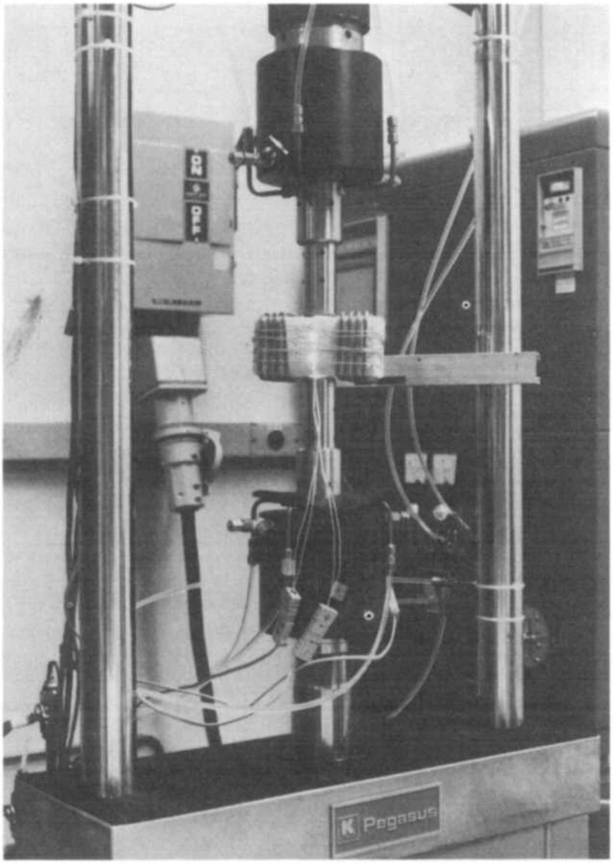

Fig. 1. Load-train column assembly installed on a universal testing machine for tensile testing of ceramic specimens heated by an induction heater.

1000°C for many nickel-based superalloys. A load-train assembly as shown in Fig. 1, was developed by Liu & Brinkman (1987) for testing ceramics with low thermal conductivity.

2 METHODS OF INDUCTION HEATING

A metallic tensile specimen can be heated by an induction generator using a water-cooled copper coil centred around the specimen as shown in Fig. 2(a). The heat input is focused in the gauge section of the specimen. The temperature profile along the gauge length is tailored by varying the number, diameter, and spacing of the coil loops. The design flexibility of the induction coil is an advantage of this method in heating the specimen for mechanical testing.

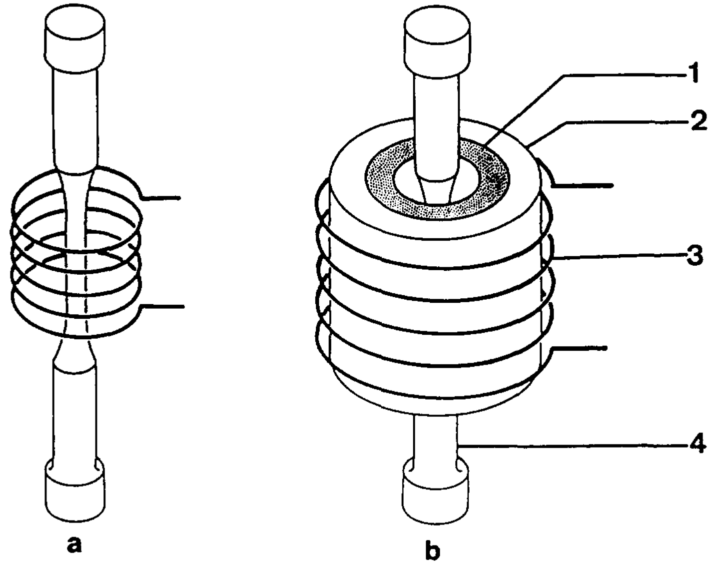

Fig. 2. (a) Basic method of heating a metallic tensile specimen by induction power; (b) method of heating nonconductive ceramic specimen by induction with a SiC tubular susceptor.

For testing ceramic materials which are not electrically conducting, direct heating by induction power is not feasible. Another heating strategy is illustrated in Fig. 2(b); a susceptor (1) is inserted as an intermediary between the specimen (4) and heating coil (3). Any metallic as well as nonmetallic conductor can be used as the susceptor provided that it can be heated above the test temperature. A section of a silicon carbide bushing having a 40-mm OD by 20-mm ID and a length of 50 mm is used in the ORNL induction heater. When the power is turned on, the susceptor is first heated by the induction coil which, in turn, heats the specimen by thermal radiation. The susceptor is insulated by means of a concentric firebrick bushing (2). Using this heating method, we have heated a silicon nitride tensile specimen to 1400°C. To minimise the heat loss further, both ends of the heater are also insulated with firebrick covers, which are not shown in Fig. 2b.

It should be noted that this elementary approach of induction heating may not be practical for routine testing and in some instances may be troublesome. Several drawbacks can be cited. First, the centre portion of the gauge section reaches a higher temperature than the end portions. As a result, the uniformity of the temperature distribution along the gauge length is usually less satisfactory. Second, because of the tight coil configuration it has always been difficult to make instrument ports for an optical pyrometer and a strain extensometer without coil interferences. Third, it is difficult and

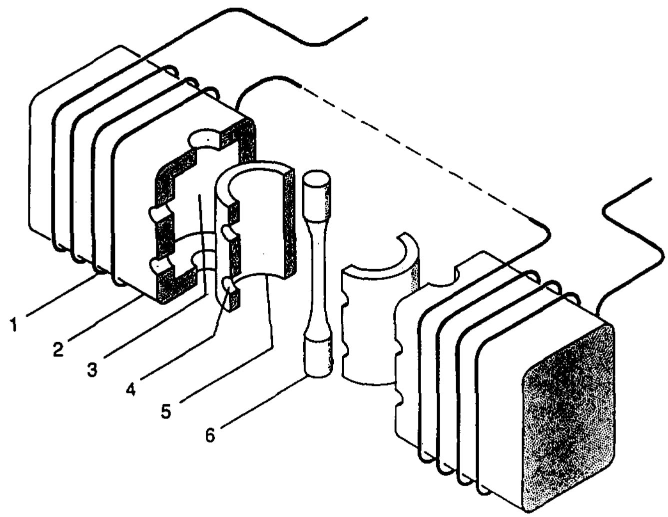

Fig. 3. Modified method of heating a ceramic specimen by induction with a pair of SiC clamshell susceptors.

cumbersome to assemble the load train with the coil assembly fixed in the testing position.

To facilitate routine tensile testing, another coil configuration, shown in Fig. 3, has been developed for heating ceramic materials. The tubular susceptor (5) is sectioned into two halves along its longitudinal axis so that each can be removed when the heater is not in use. Basically, this modification has made this heating system into a split clamshell furnace operated by induction power. To heat the split susceptors effectively the induction coil (1) is laid horizontally with the windings separated in two sections to clear the load-train column. The susceptor shell is a press fit in the cavity (3) and cemented at the inner surface of the firebrick (2), which in turn fits inside the coil opening. The firebricks are held together by fibreglass chord as shown in Fig. 1. The circular notches (4) on the front edges of the susceptors and firebrick insulators act as instrument ports through which the temperature and strain in the specimen are measured.

3 INDUCTION POWER GENERATOR AND COIL

The induction heating coil described in the preceding section is made of 5-mm diameter copper tubing, cooled by chilled water. Each piece of the SiC half-shell is heated with a winding consisting of four turns of rectangular coil having an opening of 65 mm by 75 mm, as shown in Fig. 4. The maximum

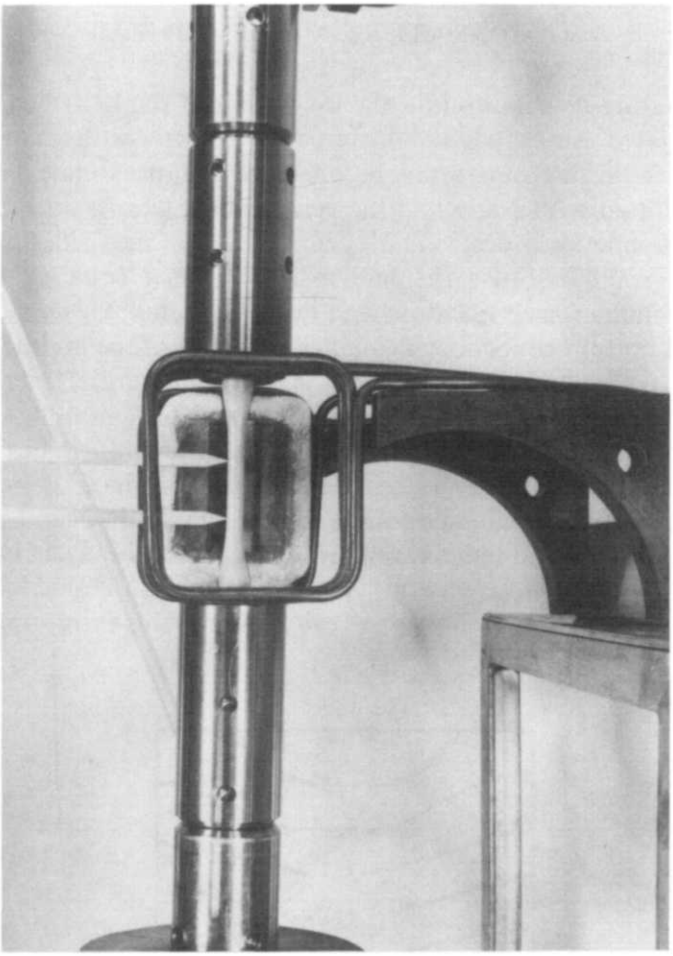

Fig. 4. Side view of the induction heater with one side of the heating block removed from coil windings. Leaning against the specimen from the left are a pair of strain extensometer probing rods.

heating efficiency is obtained through experimental tuning of frequency and inductive coupling between the electric properties of the object and the coil geometry.

The varying magnetic field required for induction heating is produced by alternating current flowing in the induction heating coil. An important part of the information needed for selecting the power supply is the determination of the best frequency for a given situation. The frequency of the alternating current ranges anywhere from kilocycles to megacycles. The power supply selected for ORNL's ceramic testing has a maximum output capacity of 2·5 kW and an operating frequency range between 160 and 800 kHz. This unit is capable of heating silicon nitride to 1400°C.

4 TEMPERATURE MEASUREMENT

The temperature distribution on the inner wall of the half-shell susceptor was investigated using a two-colour optical pyrometer with accuracy better than 1% of full scale temperature. Figure 5 shows approximate temperature contours plotted with respect to the centre point temperature at 1200°C. The lowest temperature occurs at the centre region of the shell. This is not an unexpected result because the half-shell is framed squarely inside the rectangular induction coil as shown in Fig. 4. As a result, the temperatures at the top and bottom edges become higher than that of the middle region by about 25°C, equivalent to about 2% of the shell temperature. Interestingly, it should be pointed out that this seemingly detrimental behaviour of nonuniform thermal pattern is actually beneficial to uniform heating of the specimen. An obvious reason is that the extra heat produced at both the top and bottom edges is a valuable source of heat supply that can be used as a means to minimise the temperature gradient normally occurring at both ends of the uniform gauge section. The midportion of the side edges is also slightly hotter than that at the centre region. Again, this extra supply of heat

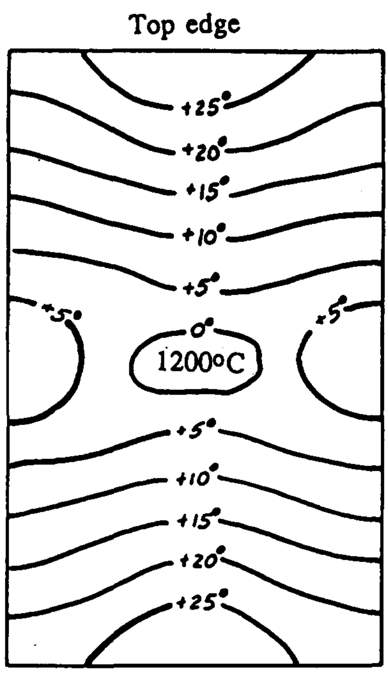

Fig. 5. Approximate temperature contours on the inner surface of the half-shell, plotted with respect to the centre region temperature at 1200°C.

is also beneficial in balancing out some heat loss at the seam between the firebricks.

A silicon nitride tensile specimen was then heated with the clamshell induction heater and the temperature gradient along the gauge length measured with three type-S thermocouples. One was attached to the centre and the remaining ones at both ends, about 10 mm from the centre. Concurrently, the temperature gradient on the specimen was measured with the two-column pyrometer which gave agreement within about $\pm 1\%$ with the thermocouples. Temperature measurements were made at three steady state levels of heating at nominally 800, 1000, and 1200°C. Results showed that the temperature differences between the centre and ends were about 25, 20, and 10°C, respectively: the temperatures becoming more even at the higher level of heating. The 25°C gradient is equal to about 3% of the specimen temperature, which may be acceptable for fast-fracture tensile testing.

5 CONCLUSION

A method of induction heating has been described for ceramic materials testing and the case argued that it is a simple, versatile, and effective method that is particularly suited for use in testing ceramic materials with low thermal conductivity. Compact geometry, tailored heating, and ease of access to the specimen for temperature and strain measurements are other features that cannot be offered by the conventional resistance furnaces. Induction heating offers fast temperature rise times and is, therefore, suitable for thermal cycling and thermal fatigue investigations. Additionally, it permits the use of metal alloy fixtures for specimen gripping which is clearly an economic advantage for this method of heating.

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REFERENCE

Liu, K. C. & Brinkman, C. R. (1987). Tensile cyclic fatigue of alumina at room and elevated temperatures. In *Proceedings of the 24th Automotive Technology Development Contractors' Coordination Meeting*, Dearborn, Michigan, October 27–30, 1986, Society of Automotive Engineers, Warrendale, Pa, p. 197.