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ACOUSTIC EMISSION IN REFRACTORY MATERIALS

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ABSTRACT

Refractory materials have an extremely heterogeneous structure which, under stress, gives a high output of acoustic emission of the "burst" type. Three types of stressing are discussed in this paper. They are 1) Cold-Crushing. 2) Thermal Shock. 3) High Amplitude Cyclic Torsional Testing.

Acoustic emission affords a useful means of following progressive internal damage up to the failure point. However the variability of the test material makes quantitative analysis difficult so that the tests are mainly comparative.

1. INTRODUCTION

The ceramics industry has known of acoustic emission for thousands of years.The early potters when drawing (unloading) their kilns would often hear 'pinging' or crackling noises. Today this phenomenon is known as 'dunting' in the pottery industry or 'spalling' where refractories are concerned. It arises from the effects of thermal shock, the energy release being so great as to produce high level acoustic emission in the audible range. Acoustic emission now provides a means of following the phenomenon through its various stages.

2. TECHNIQUES

2.1. Specimens

The type of refractory materials to be discussed are the 'tonnage' refractories which comprise bricks and shapes used in the construction of furnaces, kilns and ovens. Special ceramics such as alumina, silicon nitride and silicon carbide have not been tested.

A typical refractory has a complex structure which may have a porosity as high as 50%. The structure of the alumino-silicate type is usually grain-matrix in character. The matrix is an alumino-silicate glass which is normally highly cracked. The grains may vary in size from a few micrometres to more than ten millimetres across. An extensive crack system is usually present and here again the size may range from micrometres to tens of millimetres. Fissures and laminations are often present. The basic refractories (magnesite, chrome-magnesite, mag-chrome) have a structure consisting of large grains cemented together either by direct grain to grain sintering or by small amounts of silicate material.

These structures make any study of crack propagation difficult since the pores or grains act as efficient crack stoppers. They do however provide optimum conditions for the production of acoustic emission.

Types of specimen used include - whole bricks for thermal shock tests, blocks cut from the bricks for cold-crushing tests, bars - square section for transverse loading (modulus of rupture) or with the centre section ground to a cylinder for high amplitude cyclical torsion testing.

2.2. Equipment

The amplitude of the acoustic emission is high when compared with the levels found when testing metals. This simplifies equipment design because the gain levels are low enough to make electrical interference (such as from furnace thyristor controllers) relatively unimportant. A commercial differential transducer with an associated low-noise preamplifier is followed by a 0-40 dB variable gain amplifier with a 100 KHz high-pass filter. The output is divided into two channels. One channel feeds a variable-level pulse-height discriminator and then a count-rate meter and chart recorder. The other channel feeds a commercial tape recorder and a 0-200 KHz level recorder. The response of the tape recorder is 3 dB down at 25 KHz but despite this restricted frequency range useful recordings have been obtained. This is because the emission, which is of the 'burst' type, usually occurs in "packets" of bursts so that the tape recorder may be acting as a form of envelope detector. The level recorder results show that the emission signal level at the transducer output may rise in occasion to the region of one volt. Typical levels are well into the millivolt range.

3. TEST METHODS AND RESULTS

3.1. Cold Crushing

The first acoustic emission tests were made on firebrick blocks loaded in compression at a fixed rate to the failure point. The results resemble those obtained by SCHOLZ(1) on rock specimens. There is initially a high rate of emission probably associated with the crushing of surface irregularities (levelling) followed by a stage of low rate of emission the rate only rising slowly. The high inhomogeneity of the material ensures the presence of numerous stress concentration points so that localised failure occurs at low overall loading. This second stage usually extends from about 5% to about 30% of the failure load. In the third stage the count rate begins to accelerate probably due to the propagation of microcracks. At about 80% -90% of the failure load the increase is extremely rapid and the rate may exceed 10^5 counts per second immediately before failure, the energy output being high enough to become audible. The increases in stages two and three are not smooth the curve being more like a band with very rapid rises and falls in the emission. In stage four there are momentary discontinuities of the 'stick-slip' variety probably due to small-scale failure.

The 'Kaiser effect' is very marked in these tests. Reducing the load results in an immediate cessation of high amplitude emission with a rapid drop in low amplitude emission. On restoring the load appreciable emission is not recorded until about 80%-90% of the load at which the test was stopped.

The heterogeneity of the specimens makes it difficult to carry out these tests on anything other than a strictly comparative basis. The load/emission rate curves for similar specimens although generally of the same shape will usually show wide differences in the count rates for a given load.

Transverse loading (modulus of rupture) tests on square section bars give similar results to those for blocks, the main difference being that since the stressed volume is smaller, the emission output is lower.

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3.2. Thermal Shock

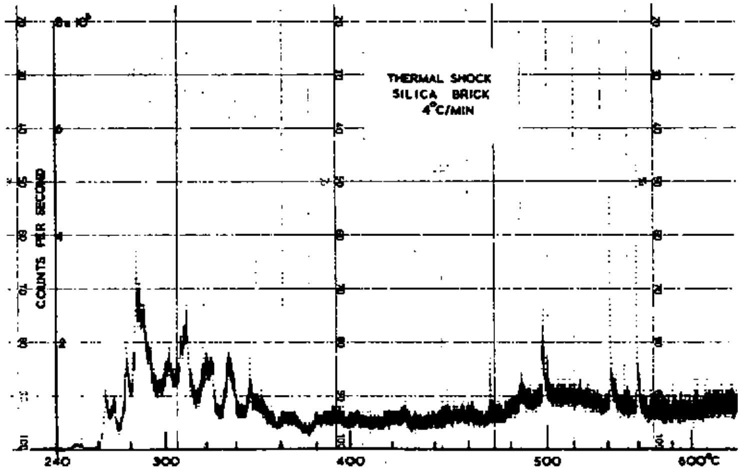

Fig.1 Acoustic Emission during Thermal Shock

Resistance to thermal shock is a parameter of vital importance in furnace design. It affects safe heating or cooling rates on the one hand and on the other hand it determines loss in structural integrity caused by 'slabbing' i.e. the detachment of portions of the heated face of the brickwork. The parameters involved are many and include; thermal conductivity, specific heat, thermal expansion, modulus of elasticity, Poisson's Ratio, shape, thermal gradient, external stresses, crystalline phase inversions, internal structure and texture among others. Usually only the final failure stages are directly observable but acoustic emission has made it possible to study the earlier stages.

The tests were made on standard sized bricks (215x102.5x65mm), the brick being set into the wall of a furnace so that only the 102.5x65mm face was directly heated, the rate of heating being constant. Under these conditions a temperature gradient will build up over the first few centimetres behind the hot face. This will cause the heated portion to expand while the rest of the brick remains unaltered. As a result of this differential expansion a compressive/tensile boundary will move backwards from the hot face its speed being dependent on the rate of heating and the thermal conductivity. The degree of microfracturing so produced will depend, among other factors, on the steepness of the gradient.

If the heating rate is high enough the resultant stresses will be sufficient to cause failure in a spherical plane behind the hot face. The process can be complicated by the presence of crystalline phase inversions which may take place as the temperature wave moves through the brick. A silica brick may contain about 35% of cristobalite. Between 200^0 and 280^{o}C α cristobalite changes to β cristobalite with a volume change of +3%. Considerable stresses will be set up if the heating rate is too high in this region.

Fig.1 is a direct copy of the acoustic emission/temperature curve for a

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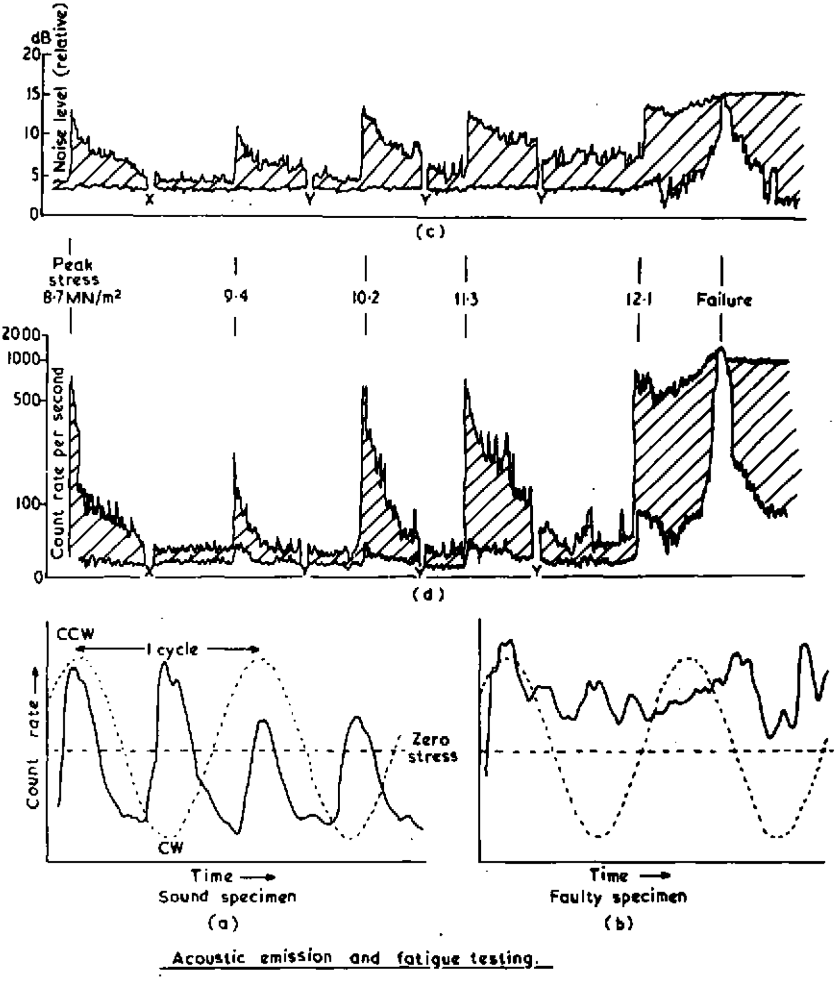

Acoustic emission and fatigue testing.

Fig. 2

silica brick heated at 4°C/min. There is very little emission below 240°C but by 360°C the main failure is complete. Secondary cracking is indicated by peaks at 500°, 540° and 560°C. On examining the specimen it was seen that the first 30 mm had slabbed away and there was extensive cracking 70mm from the original hot face. Here again it is difficult to get accurately reproducible results but the emission level rises with higher heating rates.

3.3. High Amplitude Cyclic Torsional Tests

Fig.2 shows typical results for specimens tested at 24 cycles per minute. In general there is an initial high level of emission which falls off with successive cycles. (X and Y indicate gaps in the recording of 20 and 30 cycles). The shading indicates the upper and lower emission levels on each cycle. When the peak stress is increased there is another sharp rise followed by a fall off. This seems to indicate that the major damage occurs on the first stress reversals after which the microcracks simply open and close. Further damage can only occur if the peak stress is increased. At 12.1 MN/m^2 we get macrocrack formation and failure after which the emission is mainly due to rubbing of crack edges.

Fig.2a shows two cycles in detail for a sound specimen. The emission is at a maximum at the peak stress points and minimum at zero stress giving two roughly equal peaks per cycle. Any microcracks will be symmetrically arranged. In Fig.2b the specimen was already flawed before testing and there are subsidiary peaks at the zero stress points because the cracks do not open and close symmetrically.

4. CONCLUSION

Refractory products with their heterogeneous structure provide good specimens for acoustic emission work. However this type of structure makes detailed analysis difficult because of its variability. The complex nature of the structure gives rise to numerous reflections and scattering of any emission signals. The high acoustic loss of the material effectively filters out the higher frequencies so that the transducer signal consists of packets of burst emission. For this reason the tests described have been mainly comparative in nature.

ACKNOWLEDGMENT

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REFERENCE

1) Scholz C.H. Bulletin of the Seismological Socy. of America 58 399-415 (1968) Journal of Geophysical Research 73 1447 1968.