IMPACT RESISTANCE OF SUPERALLOYS AT GAS TURBINE OPERATING TEMPERATURES

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A system for performing Charpy impact tests at high temperatures has been developed for use in the assessment of the capability of gas turbine blade materials to resist foreign object damage. It consist of a conventional pendulum type tester adapted to allow direct current heating of the specimen. The system provides an effective and economic means of performing tests on all types of high temperature alloys at temperatures up to 1200°C. In particular it avoids the need for time-consuming pre-heating and transfer of specimens from a furnace to the test point. Initial results obtained for the superalloy IN-738LC confirm the tendency of ageing to reduce the high temperature impact strength, in accordance with literature data.

INTRODUCTION

Impact resistance is important for superalloys used for gas turbine blading in particular as a result of the need to withstand foreign object damage (FOD) due to the presence of "objects" in sucked into the gas stream. The nickel-base superalloys typically used in such applications possess only a modest impact resistance in the virgin state (a Charpy impact energy in the range 10-20 J would be normal) and a rule-of-thumb value of 8 J has been suggested (1) as a minimum for adequate resistance to FOD in service conditions. A number of studies have shown that in-service ageing (1,2) or in some cases environmental attack (3) can lead to more than a 50% reduction of the initial value, indeed to below the 8 J critical level. Two further factors underline the need for high temperature impact testing. Firstly, such testing provides a basis for establishing a correlation between the evolving microstructure and the degree of embrittlement in laboratory aged specimens, potentially providing a non-destructive means of assessing such effects

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in components. To date such correlations tend to be material specific (2) and not readily transferable to other alloys. Secondly, test evidence indicates that the loss of impact strength accompanying microstructural ageing can be detected only at temperatures typical of those encountered in service (700°-850°C) and not in room temperature tests.

TEST APPARATUS DEVELOPMENT

Conventionally impact testing at high temperatures involves pre-heating the specimens in a furnace and then transferring them to the test machine for the test itself. A more elaborate variation this is described by Pard (2) who used a drop weight tester modified to accomadate a muffle furnace which surrounds the anvil and maintains the specimen at a constant temperature. The striker comes down through an aperture in the furnace to fracture the specimen. The load response is measured remotely to calculate the fracture energy.

In a recent programme devoted to developing residual life estimation techniques for gas turbine components on behalf of ENEL (the Italian electricity company and a gas turbine operator) CISE decided on an alternate approach. Building on extensive experience in impact testing of ferritic steam turbine rotor steels, a direct current heating method was opted for. The resulting modified Charpy pendulum impact rig used is shown schematically in Figure 1. The specimen sits against the anvil on top of two copper bars through which a transformer supplies high current at low voltage (about 150 A at 1.5 V will heat a specimen to 900°C, although temperatures of up to 1200°C are possible). The electrical contact between the specimen and the copper bar terminals is maintained using a spring loaded arm which keeps the specimen pressed down against the copper bars without obtructing its movement at impact; indeed preliminary tests at room temperature with and without the retaining bar produced identical impact energy values. A type K thermocouple spot-welded close to the notch root is used to monitor the temperature. The specimen can be heated quickly to the required temperature; typically it takes about 3 minutes to reach 900°C in a controlled manner. Once the required temperature is reached, the impact test is performed in the normal manner, with the impact energy being read from the dial or alternatively calculated from the load-time response of the instrumented skriker head. An accuracy of ±0.5 J is obtained.

The system appears to offer significant economic and time-saving advantages over the muffle furnace heating procedure described above. At present standard 55x10x10mm Charpy test bars are being used, but the heating method is highly suited for use with miniature specimens (machined from a serviced turbine blade, for example).

TABLE 1 - Influence of Ageing on the Impact Resistance of IN-738LC.

Duration of Ageing at 950°C	-	24 h	24 h	72 h	125 h	274 h	346 h
Impact Energy at RT, J	9.0	11	14	15	15.5	8.5	10
Impact Energy at 900°C, J	8.5	6.5	8.8	7.5	7	6.5	5.5

RESULTS AND DISCUSSION

To commission the system, a series of tests has been carried out on the cast nickel-base superalloy IN-738LC, widely used in industrial gas turbine blading. Specimens were tested in the virgin condition and after accelerated ageing treatments at 950°C of progressively increasing duration, carried out in a separate muffle furnace. For each condition two impact tests were performed, one a room temperature and one at 900°C. The values of impact energy, J, are given in Table 1. Presented graphically in function of ageing time, Figure 2, it is apparent that the ageing process has no detrimental effect on the room temperature impact resistance. The test results obtained at 900°C indicate however a modest decrease in impact energy to a range below the suggested 8.1 J limit.

Microstructural investigations to pinpoint the mechanism responsible for this tendency have proved largely inconclusive to date. The morphology of the fracture surface was predominantly interdendritic in all the specimens examined (see for instance Figure 3). Metallurgical examination of the aged specimens revealed the expected microstructural changes associated prolonged exposure to high temperature: coarsening of the primary γ', depletion of secondary γ' particles and increased interdendritic precipitation. It remains unclear as to why such phenomena apparently only affect the high temperature impact energy.

Pard (2) has suggested the use of an ageing time-temperature parameter analogous to the Larson-Miller parameter used in creep rupture analysis:

$$P = \frac{T(^\circ K)}{1000} \cdot \left[20 + \log_{10}(t_{ageing}) \right]$$

to correlate the impact energy of specimens aged or exposed in service for different durations and at different temperatures. Figure 4 shows the present high temperature data plotted in this manner, together with data for IN-738LC from the literature (1). Reasonable agreement is obtained between the results for the laboratory aged specimens.

CONCLUSIONS

A direct current heating method for performing Charpy impact tests at high temperatures (up to 1200°C) has been developed which provides a time effective and economic means of performing such tests on superalloys typically used in gas turbine blading. Initial results obtained for the superalloy IN-738LC confirm the tendency of accelerated ageing to reduce the high temperature impact strength.

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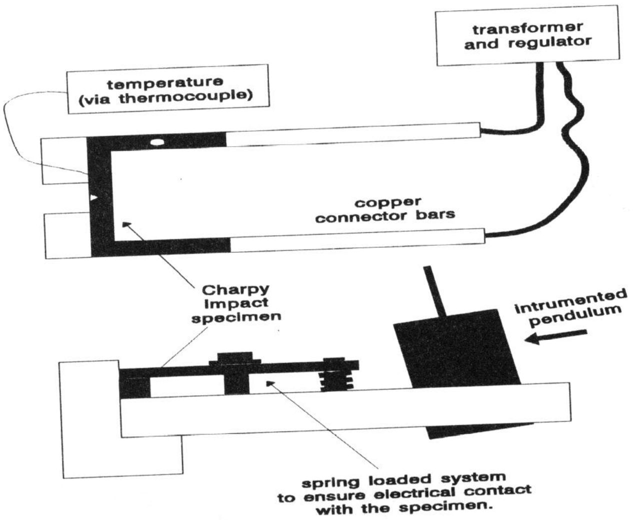

Figure 1. Schematic of the high temperature impact test system developed at CISE.

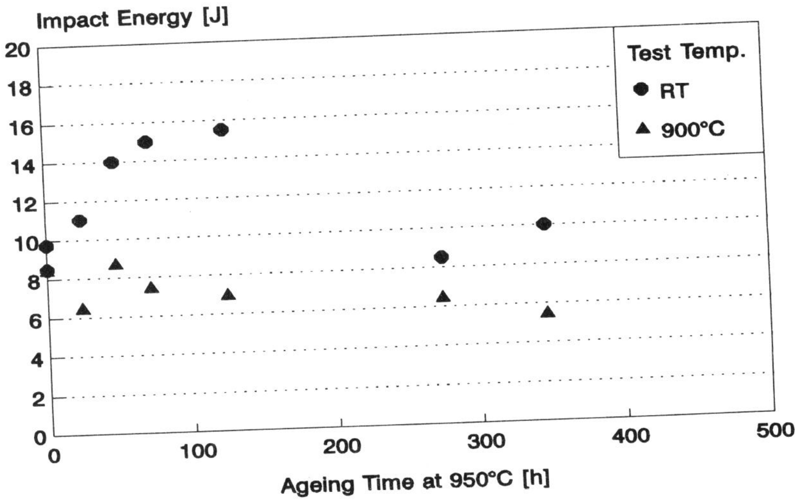

Figure 2. Impact resistance of IN-738 at room temperature and 900°C as a function of aging time at 950°C.

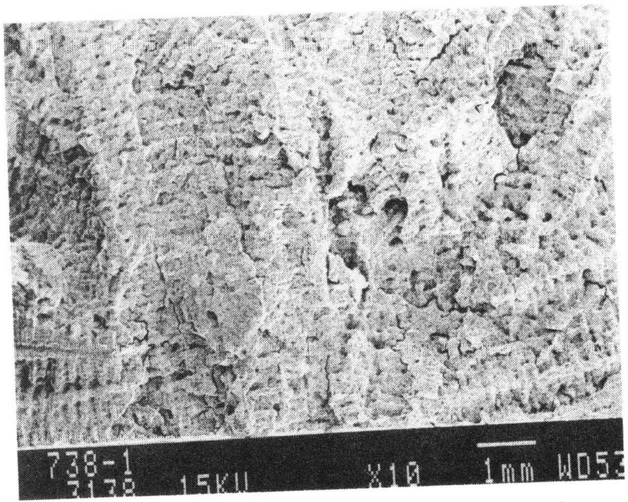

Figure 3. Interdendritic nature of the fracture surface of a virgin specimen tested at room temperature.

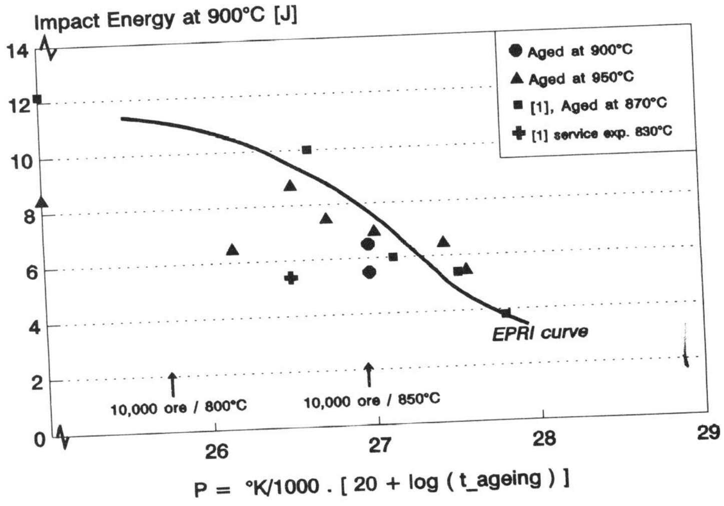

Figure 4. Loss of high temperature impact resistance correlated in terms of a time-temperature parameter analogous to that of Larson-Miller.