INTRODUCTION

Many high temperature turbine components are subjected to rapid temperature changes during start-up and shutdown, leading to nonuniform heating and cooling. Repetition of such thermal loadings leads to thermal fatigue in critical hot section components such as blades, vanes, shrouds and combustors. This type of thermal fatigue is one of the primary failure modes that must be considered in turbine design and analysis.

A number of approaches to thermal fatigue analysis have appeared over the years.¹,²,³ For the most part the emphasis in these is on assessing the damage to produce cracking. Little attention has been given specifically to the treatment of crack propagation, despite the fact it would appear that this is the primary damage process. Thermal fatigue loadings generally produce high strains and cracking commences in very few cycles. Further, the thermal stress fields generally involve strong gradients, so that the subsequent crack propagation rates may decay as the crack extends. Hence, in thermal stress problems it would appear important to develop tools for assessing crack propagation, as well as crack initiation.

Quantification of the thermal fatigue damage process requires highly complex analysis when temperature and loading conditions induce nonlinear deformations. The analysis must consider the nonuniform, 3-dimensional geometry in the thermal and stress...
analysis, factor in material property variations with temperature, and account for the accumulation of time independent and time dependent nonlinear deformation.

The present paper explores some analytical methods for treating the overall problem, including the separation of the crack initiation and crack propagation phases of life. Emphasis is placed on simplifying the analyses so that they can be carried out economically. The analysis methods are used to examine the results of thermal shock tests on tapered disks.

TAPERED DISK TESTS

Thermal shock tests were conducted on the tapered disk specimen design shown in Fig. 1. Many of the test results have been reported in earlier papers.\(^4\),\(^5\),\(^6\),\(^7\) The specimens are subjected to alternate heating and cooling shocks by immersion in fluidized baths. The fatigue process in tests of this type is expected to be similar to turbine hot-section thermal fatigue, because of the similar strain-time-temperature histories.

The fourfold variation in peripheral radius \((R_p)\) indicated in Fig. 1 was incorporated as a means for achieving a variation in cyclic stress range for fixed minimum and maximum bath temperatures. For the tests analyzed herein, the cold bath or minimum temperature was always held at 70\(^\circ\)F for an exposure time \((t_c)\) of 4 minutes.

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![Fig. 1. Tapered disk thermal fatigue specimen.](image-url)