Proc. National Seminar on
Non-Destructive Evaluation
Dec. 7 - 9, 2006, Hyderabad

NDE of Aerospace Components

R.P. Singh, E. Madhava Rao and N. Vijay Shankar
Defence Metallurgical Research Laboratory, Kanchanbagh (PO), Hyderabad-500058.

Abstract

Investment cast aerospace components are prone to defects related to solidification process. The hollow columnar-grained aero engine Vane casting, being discussed in this paper, suffers further from extraneous defects such as inclusions, core shift and resultant dimensional deviations. Due to its design complexity and stringent specifications, non-destructive evaluation (NDE) of this component is extremely difficult and critical. Complete inspection, employing different non-destructive testing (NDT) techniques, has been aimed to assess full inspectability and reliability of the components. Radiography, visual/ grain size inspection/ fluorescent dye penetrant test (DPT) after macro etching of the components, and ultrasonic wall thickness measurement (with an accuracy of ±0.02 mm) of the aerofoil are the techniques utilized for complete inspectability. Innovative NDE methods and specially designed equipments have been used for the purpose.

Key words: *Radiography, Dye penetrant test, Ultrasonic thickness measurement, Shrinkage porosity and cracks.*

1. Introduction

The aerospace component under discussion is a Nickel base super alloy investment cast directionally solidified hollow high pressure Turbine Vane, developed in Defence Metallurgical Research Laboratory, Hyderabad, for application in Kaveri Engine [1]. NDE of such a critical component plays a major role in certification for service reliability. In view of the fact that this component has to withstand very high temperature when the engine is in flight, innovative NDT methods have been developed for its evaluation. The defects developed during solidification process are shrinkage porosity, cracks, hot tears and grain structure related defects. Inclusions come from extraneous sources like mould and core materials. Ceramic core introduced in the wax pattern for making hollow casting, sometimes, during wax-injection or during metal pouring, shifts from its original position causing major dimensional deviations in the over all profile. Due to this core shifting, many times, the thin aerofoil portion of the casting breaks or remains unfilled, referred to as “kissed out”.

Radiography evaluates the internal soundness, the visual/ fluorescent dye penetrant inspection reveals surface and sub-surface defects and the ultrasonic thickness measurement indicates dimensional inaccuracies/ deviations in the component.

2. NDE Techniques/ Principles

2.1. Radiography: When X-rays (short wavelength electromagnetic radiations) pass through an object there is differential absorption of penetrating radiation (energy) depending upon the object material, its thickness/ orientation and the internal flaws present in the object. The basic set up consists of a radiation source, the object to be radiographed and a detecting medium (radiographic film or a screen) [2]. The effective parameters are strength of the source, focal spot size, frequency of radiation and film-focal distance. The exposure time, film quality (speed) and film processing technique affect the film density, the film/ image contrast and sensitivity. Time of exposure is directly proportional to source to film distance and inversely to the source strength (Curies) and radiation output (Roentgen per hour by one curie at 1 m).

Fig.1 shows the turbine vane component under consideration. According to the changing profiles, in terms of thickness and orientation, a number of radiographic exposures had to be designed and standardized for effective radiographic evaluations. Innovative ideas were put to develop the exposure techniques. For the aerofoil portion (concave at one side and convex at the other side) single film single image technique was applied, also upside down. Again for the trailing edge and the leading edge separate exposures were designed. A high energy, high frequency 450 kV X-ray equipment having dual focal spot (1.5 mm & 4.0 mm) is being used for the purpose. Focal spot (target) is the area of the anode of X-ray machine which is struck by electron flux. With 1.5 mm focal spot and 4.0 mA current the voltage was varied from 105 to 190 kV for different 13 exposures. Wire type DIN penetrameters (Image Quality Indicators) were used to assess the sensitivity of exposures. To assess the flaws of size 0.25 mm and above, 16^{th} DIN wire (0.10 mm dia) was used.

2.2. Visual examination & Grain size evaluation:

Fettled, heat-treated and sand blasted components are examined for any visual defects. Isolated and clusters of pores are examined. With lot of restrictions of numbers/ clusters and spacing, a maximum of 0.5 mm size defect on the aerofoil has to be identified. On the shrouds and flanges, a maximum of 1.5 mm defect with 3 mm spacing and 6 nos. of isolated indications per side are allowed.

After visual examination, the components are macro-etched, Fig. 1 for grain evaluation. The columnar grains are examined for their width and angles with the stacking axes. A minimum number of grains per mid span chord and the maximum grain width are specified.

2.3. Dye Penetrant test (DPT): On application or dipping, liquid dye penetrates the surface openings/ discontinuities by capillary action. The ability of a liquid to flow over a surface and enter into an opening depends on the surface tension and capillary action. After careful removal of excess dye, a thin coating of developer is applied over the surface to draw the dye out of the crack or opening to increase visibility. Visible light or ultraviolet light or laser incident light can be used for scanning the surface for any indications.

The etched and cleaned components are subjected to Fluorescent Particle Inspection (FPI) under a black light source (~ 365 nm wavelength). The aerofoil is checked for 0.5 mm or bigger defects/ indications with restrictions of clustering and spacing. Similarly the flanges and shrouds are examined for the specified indications. Metallic wires of different diameters are being used for measuring the sizes of the pores/ defects.

2.4. Ultrasonic Wall Thickness Inspection: In ultrasonic testing a piezoelectric transducer (probe) converts electrical energy into mechanical vibrations (high frequency acoustic waves) which travel through the object under inspection and get reflected from the opposite surface of the object depending upon the density/ inhomogeneities of the object and velocity of ultrasonic waves in the object material. On return, these waves enter the probe and get converted back into electrical energy that can be related to integrity of the object. In the contact method of inspection oil/ grease is used as couplant for better contact of the probe with the material under inspection. Thickness measurement uses ultrasonic transit time measurement. Since the longitudinal wave speed is constant for a given material, changes in material thickness may be determined using the position of back echo obtained from conventional normal beam inspection [3].

Wall thickness of the aerofoil of the subject Vane casting is measured with a specially designed Flaw Detector cum Thickness Gage of KrautKramer equipment. Thickness (ranging from 0.5 to 1.72 mm) at different specified locations is measured with an accuracy of 0.02 mm. A pencil probe of 3 mm diameter and 25 MHz frequency is being used with pulse echo technique and digital readout.

3. Results and Discussion

3.1. Radiography: As regards the dual focal spot of the X-ray equipment, the source strength or more precisely, the radiation output can be manipulated to have just sufficient quantum of radiation for exposing different portions of the Vane component. Focal spot size controls the geometric unsharpness of the radiographic image. The focal spot size should be as small as possible in order to achieve maximum sharpness in the radiograph [4]. But, the X-ray tube anode/ target heating limits the size of focal spot. Thus, a compromise between maximum radiographic definition and maximum target life should be reached. Although a sensitivity of 2% is universally accepted, we have been able to achieve 1% sensitivity with our set up of exposures and expertise. The defects normally observed in the subject component are porosities, shrinkage cavities, cracks, etc. The radiographs of the aerofoil are easy to evaluate because of the flatness of the object. The shrouds and their junction with the aerofoil produce very complex type of exposures where diffraction patterns cannot be avoided on the radiographs. The ghost patterns so developed took lot of our time and energy for their interpretation. Many experimental exposures on the cut pieces of the shrouds led to some conclusion and could satisfy the evaluation process.

3.2. Visual Examination: Visual inspection provides a variety of information regarding surface flaws, such as surface finish, surface corrosion, discontinuities at fabrication joints, junctions of parts/ flanges, surface cracks, etc. [5]. Even when other NDT methods are used to detect surface flaws and cracks, visual inspection is a useful supplement. In the present case also, visual inspection not only reveals general indications but also the surface depressions and positive material on the surfaces, caused by shell mould internal surface defects. The subsequent fluorescent DPT does not detect these things.

3.3. Fluorescent DPT: Black light equipment has deep red-purple filter designed to pass only those wavelengths of light that will activate the fluorescent materials [6]. This light is between the visible and ultraviolet in the electromagnetic spectrum. Thus, the harmful ultraviolet radiation is also filtered. Under the desired black light the defects are observed as the fluorescent particle patterns. Defect size measurement is a typical issue in the present case. After application of dye and developer the surface of the object is such that defect size estimation is very difficult. Idea of using different dia copper wires (0.2, 0.4 & 0.5 mm) is just brilliant. Anyway, defect length measurement is easy. Identification of the defects and their locations are recorded for reporting purpose. Defects depicted in Fig. 2 (a) & (b) are grain boundary cracks, typically related to the chemistry of the alloy and solidification process.

3.4. Ultrasonic Wall Thickness Measurement: Wall thickness of the aerofoil varies from leading edge (thicker portion) to trailing edge (thinner portion). Also, it varies from one flange to the other. Thickness is a function of ultrasonic transit time between initial and first back echo observed on the screen. Digital display of thickness (conversion of the transit time) is also there. This outcome is the comparison of the reference transit time of known thickness of the same material with that of the object under inspection, because the ultrasonic velocity remains the same. The maximum frequency that can be used for the test determines the minimum thickness that can be measured [7]. Scanning by pencil probe for such critical measurements is difficult and the normal incidence is achieved by maximizing the signal coming from the back surface. For such thickness measurements, the inspection system must be suitable for the purpose and the operator must be trained and experienced [7]. If not, gross error in inspection may result. With a little disorientation (at an angle) of the probe, erratic results may cause rejection of good components as well. The equipment being used in the present case is very special in design and capable of satisfying the inspection programme with an accuracy of 0.02 mm.

4. Conclusions

The investment cast directionally solidified (**c**olumnar grained) Nickel base super alloy high pressure turbine Vane component for Kaveri engine was developed over a period of more than a decade. Development of related NDE methods was keeping parallel paces. These methods/ techniques so developed and employed have been established after repeated and exhaustive experiments. Radiographic exposures (expertise) so developed and standardized offer complete inspectability and hence, adds to reliability of the component. Evaluation of surface and sub-surface defects by fluorescent DPT and wall thickness measurement, using specially designed ultrasonic equipment, are equally critical and have been established with lot of care and expertise.

5. Acknowledgement

The authors express their gratitude to the Director, DMRL, for his kind permission to publish this paper. The authors are thankful to those involved in investment casting and inspection of the subject aeroengine component.

6. References:

1. Hazari N., Chatterjee D. and Srirama Murty, "Casting of Columnar Grained Airfoil Component for Kaveri Engine", *Proceedings of the National Conference on Investment Casting (NCIC-2003)*, 54-61, 2004.

2. Raj Baldev, Jayakumar T. and Thavasimuthu M., "Practical Non-Destructive Testing", Second Edition, 54-76, 2002.

3. Raj Baldev, Jaykumar T. and Thavaimuthu M., "Practical Non-Destructive Testing", Second Edition, 87-90, 2002.

4. ASM Metals Handbook, Ninth Edition, 302-307, 1989.

5. ASM Metals Handbook, Ninth Edition, 3-11, 1989.

6. Lokanathan T., "Workshop on Non Destructive Evaluation Techniques (WNDE-06), IGCAR, Kalpakkam ", LPT_TL-1 to 13, 2006.

7. ASM Metals Handbook, Ninth Edition, 231-277, 1989.

Fig. 1. **High Pressure Turbine Vane showing columnar grains after etching**

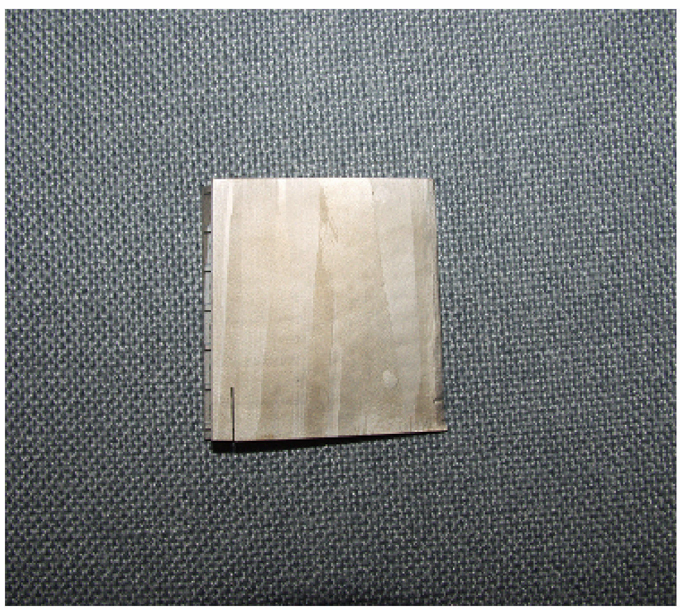

Fig. 2(a). Showing etched columnar grains on the aerofoil.

Fig. 2(b). Showing grain boundary cracks in Fluorescent DPT.