L.2: Fatigue and Fracture Characteristics of Laser Rapid Manufactured Inconel 625

Laser Rapid Manufacturing (LRM) is an attractive tool for fast and economical fabrication of three-dimensional functional components. As LRM process involves layer by layer deposition in an open atmosphere, the as-fabricated components have oxide inclusions and micro-porosity. Moreover, the process, because of its inherent method of fabrication, involves cast microstructure with associated texturing and segregation effects. All these factors are likely to influence fatigue and fracture behavior of laser rapid manufactured components. The present work, carried out in Laser Materials Processing Division, involved fatigue crack growth rate (FCGR) and fracture toughness characterization of laser rapid manufactured structures of Inconel 625 (IN 625). These studies are essential to ensure the structural integrity of laser fabricated parts for implementation of LRM as an alternate low volume fabrication process. Various stages involved in fabrication of compact tension (CT) specimens for evaluation of fatigue and fracture toughness are shown in fig.L.2.1. Final machined CT sample is shown in fig.L.2.1D.

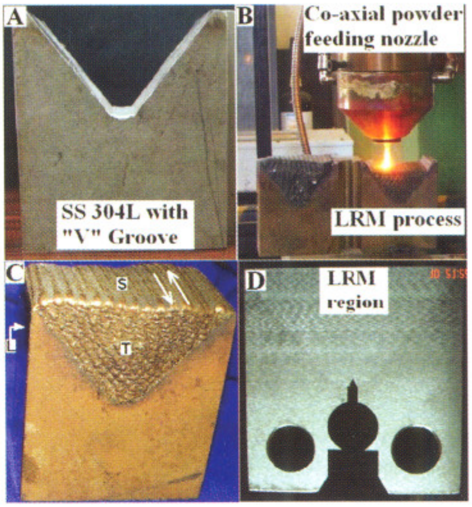

Fig.L.2.1:Sequence of steps involved in the fabrication of compact tension (CT) specimens of Inconel 625.

Fatigue and fracture toughness measurements were performed on 12 and 25 mm thick CT specimens (width, W = 50 mm), as per ASTM E 647 and E 1820, respectively. After FCGR tests, same CT specimens, with desired fatigue crack length as per the ASTM standard E1820, were subjected to J-integral fracture toughness testing by single specimen unloading compliance technique. Fatigue crack growth in LRM specimens of IN-625 was characterized by steady crack growth (Paris' regime) in the investigated stress intensity range (ΔK) of 14-38 MPa$\sqrt{m}$. In the ΔK range of 14-25 MPa$\sqrt{m}$, fatigue crack growth rate in laser rapid manufactured specimens was lower than that reported for wrought IN-625 as can be seen in Fig. L.2.2. Inset of this figure shows fine fatigue striations, which indicates ductile nature of crack growth. J-integral test was associated with stable crack growth without pop-in behavior. The J integral fracture toughness values ($J_{0.2}$) for 12 mm and 25 mm thick specimens were found to be 225-255 and 196 kJ/m^2 respectively. Figure L.2.3 presents dimpled fracture surface of J-tested region of CT specimen. This study demonstrates that LRM can be used to fabricate functional metal structures of IN 625 with adequate fatigue strength and toughness.

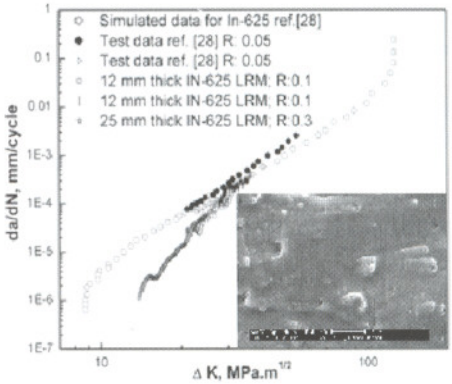

Fig.L.2.2: Comparison of FCGR data of LRMed IN 625 with that of reported data.

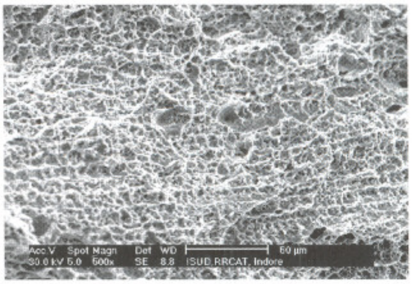

Fig.L.2.3: Dimpled fracture surface of J-tested CT specimen representing ductile crack propagation.

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L3: Studies on Copper vapour laser pumped narrow line-width Rh110 dye laser

In Laser System Engineering Division (LSED) RRCAT, a CVL pumped narrow line-width Rhodamine110 dye laser is indigenously developed. The tuning range (553 - 585 nm) of this dye laser is appropriate for selective excitation studies of isotopes of many elements including that of Ytterbium. The dye laser resonator consisted of double prism pre-expander (magnification ≈20), grazing-incidence grating (2400 lines/mm) and tuning mirror (Reflectivity ≈100%). The dye laser output power was taken through a 4% reflecting output coupler. The overall cavity length was 18 cm. The dye laser wavelength was changed by rotating the tuning mirror. A 2.0 mM dye solution of Rhodamine110 dye in ethanol flowed through the dye cell at optimized flow rate of 2.0 lpm. The dye cell was set at 5 degrees with respect to the optical axis to avoid multiple-reflection of the laser beam between the inner surfaces of the dye cell. About 5.5 W green beam (510 nm) of CVL was focused via a 75 mm focal length cylindrical lens onto the dye cell.

Results

1. Dye laser output power and tuning range

Fig.L.3.1 shows the variation of dye laser output power as a function of dye laser wavelength for the fixed CVL power of 5.5 Watt (at 5.5 kHz). The laser power was measured with a power meter (Gentec, PS- 310 WB). The peak conversion efficiency and output power at wavelength 564 nm were 9 % and 500 mW respectively. Dye laser wavelength tuning from 553 nm to 585 nm was observed.

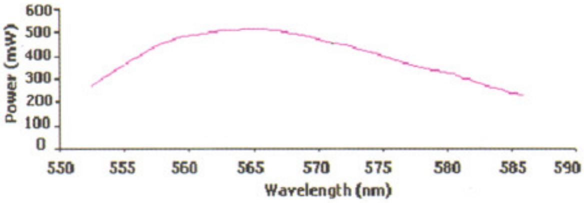

Fig.L.3.1: Dye laser output power vs tuned wavelength

2. Dye laser line-width

The line-width of the dye laser was measured by a F-P etalon of FSR 20 GHz and finesse 25. Fig. L.3.2 shows the fringe pattern of F-P etalon recorded using CCD camera and analyzed by software. An average bandwidth of 3.6 GHz was obtained.

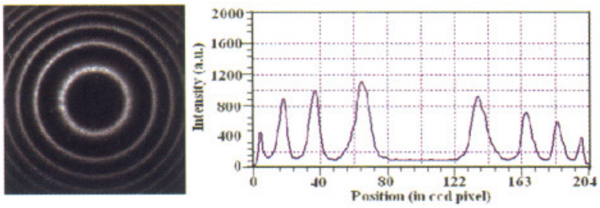

Fig.L.3.2 : Dye laser FP rings and its intensity

3. Dye laser wavelength stability

The variation of dye laser wavelength was measured with a wave meter (WS-7, Angstrom, High Finesse) and shown in Fig.L.3.3. This wave-meter trace shows dye laser wavelength stability with time. The wavelength stability of $\Delta\lambda$=0.00200 nm was noticed.

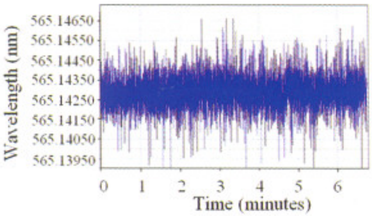

Fig.L.3.3: Variation of dye laser wavelength with time

4. Dye laser pulse shape

Fig.L.3.4 shows the pulse shape of CVL (upper trace) and dye laser (lower trace). The dye laser pulse was delayed about 5 ns with respect to CVL pulse. The dye laser pulse width was about 20 ns (at FWHM). The peak of dye laser follows the peak of CVL pulse.

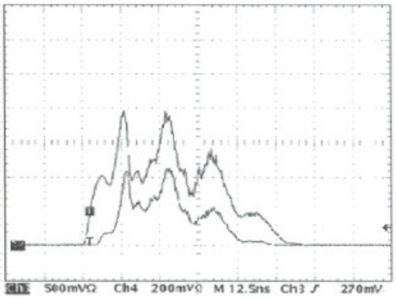

Fig.L.3.4 : Temporal profile of the dye laser and CVL

5. Dye laser beam profiles

The dye laser near and far field intensity profiles were measured. Fig.L.3.5a & b show the near and far field profiles respectively along with intensity plot. These profiles indicated good spatial beam characteristic of dye laser.

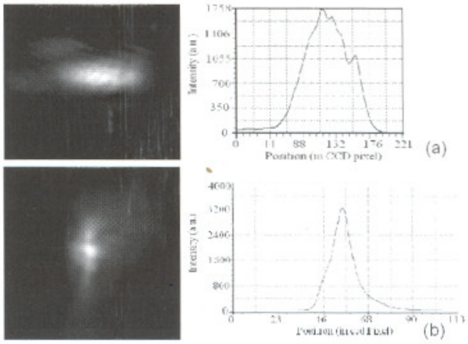

Fig.L.3.5 : Near and far field dye laser spot along with intensity profile along horizontal line

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