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# A STUDY OF THE SYMMETRY OF THERMAL STRAIN INDUCED BY LASER WELDING

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An experimental method is presented to study laser weld induced thermal strain using digital image analysis enhanced moiré interferometry. The effect of this thermal strain has significant impact on the quality and reliability of lightwave components. The results of the study show that laser weld induced thermal strain is independent of material inhomogeneity. Principal axes of thermal strain for the laser beam are determined to be offset *30°* with respect to the horizontal axis of the laser beam.

Keywords: Laser, Weld, Moiré, Interferometry.

Pulsed laser welding is rapidly gaining acceptance as a highly reliable material joining technique for precision alignments which demand high weld strength to size ratio, minimal heat affected zone and accurate positioning of the weld zone [1]. A phenomena which occurs is that the final optimum coupled power will randomly change during the weld process which may be attributed to laser weld induced thermal strain causing distortion of the components relative to one another. There exists a need to analyze this phenomena of thermal strain in order to understand the influence of material and geometry for a particular design.

Moiré interferometry [2] is based on the interference pattern generated by the interaction of a reference grating and diffraction grating applied to the surface of the specimen. Typically, cross gratings are used to measure two perpendicular displacement components. The reference grating is formed by interference of two planar laser beams, which form walls of interference lines. Before deformation, the specimen and reference grating are in phase. After an external load is applied, the reference and specimen grating are no longer in phase causing formation of moiré fringes. The displacement is determined from the relation

$$U = N / F \tag{1}$$

where $U$ is the displacement component in the direction normal to the grating, $N$ is the fringe order and $F$ is the specimen grating frequency. Strain is calculated by taking the derivative of displacement at each point along a scan line.

$$\varepsilon_x = \partial u / \partial x \tag{2}$$

Displacement can be obtained as a function of light intensity at each point along any scan line using the fractional fringe analysis equation [3]

$$U(x) = 1 / (2\pi F) \cos^{-1}\left[ ( I(x) - I_0 ) / I_1 \right] \tag{3}$$

where I(x·) is light intensity at a point, $I_1$ is the first order intensity and $I_0$ is the background intensity. Digital image processing is used in this work to record and analyze a moiré fringe pattern in order to determine the light intensity values at each point in a region.

For this investigation, *6.1mm* by *12.2mm* specimens were fabricated from *1.27mm* thick Cobalt-Nickel alloy. A wire EDM (electrostatic discharge machine) was used to prepare the samples to avoid generating any residual stresses within the specimens during machining. To investigate the influence of raw material inhomogeneity on thermal strain, all specimens were cut from a sheet in an identical orientation with respect to raw material rolling axis. A cross-grating of frequency *1200 lines/mm* was applied to the specimen and the initial moiré image was recorded in the interferometer.

Test welds were applied to with a raw material axis, $a$, in a particular orientation to the $x$-$y$ axes of the laser beam. First, the test weld was applied to the specimen with material $a$ axis parallel with the $x$ axis. Then the test weld was applied with the $a$ axis perpendicular to the $x$ axis. Test welds were applied to the specimens using a *1.06 micron* wavelength YAG laser welding facility at a power of *3.50 J*. The welded specimens were placed back into the interferometer and the final moiré pattern was recorded. Figure 1 shows the resulting moiré image of a specimen after welding. A high density of fringes is formed adjacent to the laser weld pool. Using the fractional fringe equation (3), a scan of light intensity in the region local to the weld yields the displacement distribution. The $x$-component of thermal strain, $\varepsilon_x$, is obtained by calculating $\partial u/\partial x$, at each point of the scan.

A comparison of the x and y components is shown in Figure 2. The experimental data distributions show that $x$ and $y$ components of thermal strain are independent of material orientation. Since the magnitude of thermal strain is independent of material direction, the differential between the $x$ and $y$ component indicates an asymmetry of the weld laser beam. An analysis of the weld pool shape and pattern of destroyed grating suggested the existence of principal axes of the laser beam.

Since the specimen grating maximum tolerable temperature of *150°C* is much lower than the melting point of the substrate metal, peripheral energy of the beam destroyed a certain amount of grating surrounding the weld pool. Detailed analysis of the grating damage zone using a coordinate measuring microscope indicated a principal axis orientation of *+30°* from the $x$ axis. An experiment was performed using the identical procedure mentioned above. Test welds were applied with the specimen rotated *+30°* about the center axis of the weld beam. Figure 3 shows a comparison of strain in the principle $x'$and $y'$ directions. The results show that the maximum $y'$ component of strain was approximately 9% greater than the maximum in the $y$ direction. Also, the maximum $x'$ component of strain was approximately 7% lower than the $x$ component value. The comparisons verified that thermal strain values for the *+30°* coordinate axes approach the behavior of principal values for the laser weld.

The results showed that raw material inhomogeneity due to machining processes in manufacture did not affect the laser weld induced thermal strain. Also, one component of thermal strain was significantly larger than the other orthogonal component (within a region of radius of *0.06 mm* from the weld center) at a t-test value of less than *0.02*. The asymmetric nature of the weld beam

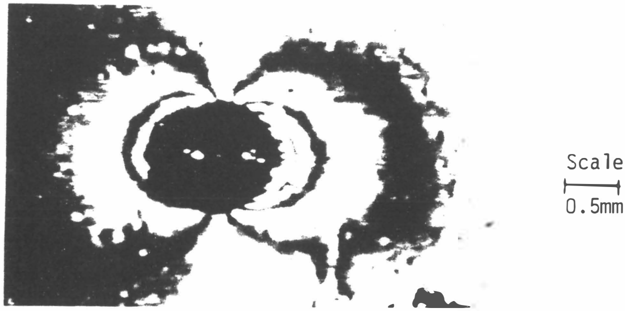


Figure 1 Final moiré image of region surrounding test weld.

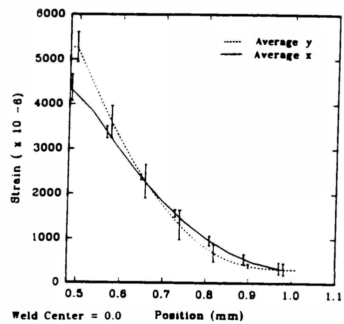


Figure 2 x-y components of strain.

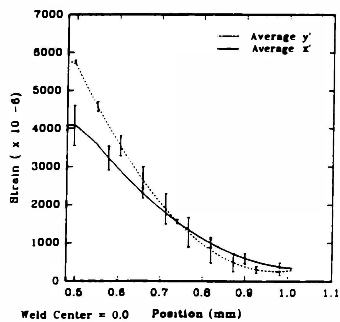


Figure 3 x'-y' components of strain

may induce unbalanced thermal strain within a welded lightwave package assembly causing distortion of precisely aligned components. Future experiments can be designed using cylindrical type specimens to simulate highly complex thermal strain problems encountered in manufacturing lightwave devices.

[1] ASM Committee on Laser Welding, Metals Handbook, 9th ed, vol.6, pp. 647-671.

[2] D. Post, and T.F. MacLaughlin, "Stain Analysis by Moiré-Fringe Multiplication," Experimental Mechanics, vol.13, no.6, pp. 253-254.

[3] A.S. Voloshin, C.P. Burger, R.E. Rowlands and T.S. Richard, "Fractional Fringe Analysis Using Digital Imaging Techniques." Experimental Mechanics, vol.26, no.1, pp. 254-258, 1986.

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