3.3.2 Cantilever Bending – Universal Fatigue Testing Machines

All fatigue testing was conducted using a SF-1-U (4450 N capacity) or a SF-01-U (890 N capacity) universal fatigue tester set up for cantilever bending, both of which operate at a constant frequency of 30 Hz. All fatigue testing was conducted using fully reversed (R = -1) load control. Both the SF-1-U and SF-01-U were calibrated with uniform diameter steel bars with a uniaxial strain gauge attached. All calibration data were acquired using a Vishay System 6000 digital acquisition system. The output from the acquisition system was used to verify the R-ratio control and that applied load was within 1% of the calculated value. The internal lay-out of the SF-1-U universal fatigue tester is shown in Figure 3.8. The oscillator, pendulum housing, compensator springs, and R-ratio adjustment are all shown. The pendulum rests within the pendulum housing, but rotates about the location labeled “pendulum” in Figure 3.8.

![Figure 3.8 SF-1-U assembly showing the pendulum housing, pendulum location, compensator springs, oscillator, and the R-ratio adjustment control (color image; refer to PDF file).](image)

Both the SF-1-U and SF-01-U fatigue testers operate in load control and can be modeled as a forced vibration with a single degree of freedom [62]. The vibration analysis is simplified because the fatigue testers operate below resonance and the differential equation used to specify the displacement is given by:

\[ M \frac{d^2x}{dt^2} + Kx = P_o \sin(\omega t) \]  \hfill (3.1)

where \( M \) is the mass of the pendulum, \( x \) is the displacement of mass \( M \), \( t \) is time in seconds, \( K \) is the overall spring constant which is made up of two components: \( K_s \) which is the specimen spring constant, and \( K_o \) which is the compensator spring constant. \( P_o \) is the amplitude of force produced by the oscillator, and \( \omega \) is the circular frequency of the oscillator force. The solution to Equation (3.1) is given by:

\[ x = x_o \sin(\omega t) = \frac{P_o \sin(\omega t)}{K - M\omega^2} \]  \hfill (3.2)
Figure 3.9  Bending fatigue set-up for the SF-1-U: (a) front view and (b) top view with the cooling air connected (color image; refer to PDF file).

The bending fatigue set-up for the SF-01-U fatigue tester is shown in Figure 3.10. The bungee cord and copper sleeve shown in Figure 3.10 were used to maintain the integrity of the fracture surface and to eliminate fretting between the sample and fixture during testing. The overall set-up of the fixture is similar to the large fatigue sample set-up with the exception that there is no cooling air applied to the sample. Even in low cycle fatigue testing, the small fatigue sample did not heat up more than 1-2 °C above room temperature so cooling air was deemed unnecessary.

Figure 3.10  Bending fatigue set-up for the SF-01-U: (a) front view and (b) top view (color image; refer to PDF file).

The temperature in the fatigue testing laboratory was maintained between 22 and 26°C. The humidity in the room was maintained below 35% relative humidity with the use of three dehumidifiers. No correlation between total fatigue life and room humidity was observed. For the majority of fatigue tests, the room humidity was below 20%.

3.3.4 Tensile Testing

Tensile testing was conducted to determine case and core tensile properties of all the induction processed conditions. Specimens were machined according to the ASTM E8-2008 standard [63] from the as-received bars of the 1045, 4145, and 1060 alloys (Figure 3.11). To simulate the core microstructures, the tensile samples were heat treated similarly to the initial heat treatments described in Table 3.2. Then, the specimens were tempered at 176 °C.