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Fatigue/Fracture Analysis of New Extrusion Method Aluminum 7075-T74

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Abstract

Purpose – This study aims to find the viability of the new method to fabricate Aluminum7075-T74.

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I. Introduction

Fatigue is a major failure mechanism of aircraft components and plays an important role in determining the reliability of the airplane. Fatigue is the failure of a material under fluctuating stresses each of which is believed to produce minute amounts of plastic strain.

Fatigue behavior of materials is usually described by a fatigue life or S-N curve in which the number of stress cycles N to produce failure with a stress peak of S is plotted against S. The particularly relevant feature of this curve is the limiting stress S, since it is assumed that stresses below this value will not produce fatigue failure however many cycles are applied, i.e. there is infinite life. In the simplest design cases, therefore, there is an aim to keep all stresses below this limiting level. However, this often implies an over-design in terms of physical size and material usage, particularly in cases where the stress may only occasionally exceed the limiting value noted above. This is, of course, particularly important in applications such as aerospace structures where component weight is a premium. Additionally the situationis complicated by the many materials which do not show a defined limit, and modern design procedures therefore rationalize the situation by aiming at a prescribed, long, but finite life, and accept that service stresses will occasionally exceed the value S. It is clear that the number of occasions on which the stress exceeds S, and by how much, will have an important bearing on the prescribed life and considerable specimen, and often full-scale, testing is required before sufficient statistics are available to allow realistic life assessment. The importance of the creep and fatigue phenomena cannot be overemphasized and the comments above are only an introduction to the concepts and design philosophies involved.

Stress-Life Approach

In this study, the stress-life approach is employed. To determine the strength of materials under the action of fatigue loads, specimens are subjected to repeated or varying forces of specified magnitude while the cycles or stress reversals are counted destruction.

In determining fatigue stress levels using standard test equipment, the test specimens are subject to alternative/reversed stresses. The cyclic stress varies from s_a tensile to s_a compressive. Fig. 1 shows the typical reversed load. The fatigue strength curves are based on this loading condition with the s_a value representing the material strength properties. We note that a stress cycle (N = 1) constitutes a single application and removal of a load and then another application and removal of the load in the opposite direction. Thus N = 1/2 means the load is applied once and then removed, which is the case with the simple tension test.
The S-N line can be expressed as

$$S_f = aN^b$$

where S_f is fatigue strength, N is number of cycles, a and b are material properties.

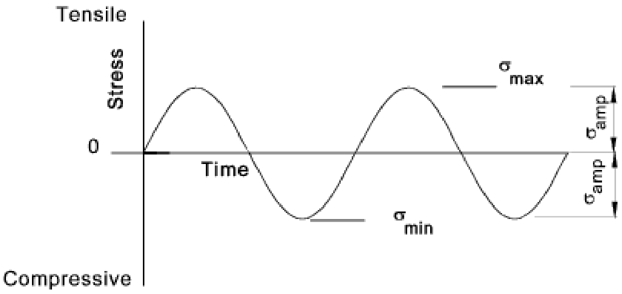

Fig. 1 Fatigue loads

Fatigue is recognized as a mechanism of crack growth terminated by catastrophic fracture - hence the S-N diagram which may be used to predict failure.

II. Experimental Setup

During this period, fatigue testing machines were tested to insure measured RPMs and applied bending moment load applied to samples were consistent with the parameters set on the machine. The results were the measured RPMs were not consistent with the set parameters and must be measured with a tachometer for every experimental run while the bending moment load set parameters were in close agreement between the actual bending moment load applied to the samples and the bending load set parameters.

The following fatigue testing machines are used:

Model: RFB200, Manufacturer: Fatigue Dynamics, Inc.

Both machines are located on a single stiff and stable support frame with vibration dampening rubber feet isolating each fatigue testing machine to reduce both vibration and noises caused by the vibrations.

Fatigue Sample Fabrication

Dog-bone fatigue samples were made with max diameter of 0.375 inch and a minimum diameter of 0.306 inch…

RPM Validation Testing

To measure and verify the RPM, an OMEGA HHT13 non-contact laser tachometer was used. The tachometer is NIST Traceable which means the tachometer and thus was tested and proven to be within the stated tolerance of accuracy with a traceable paper trail back to the NIST's standard reference materials. The non-contact laser feature of this tachometer will be used for this procedure and has an accuracy of ±0.01% of reading. For the validation and calibration, the unit measured by the tachometer was set to measure in RPS and then converted to RPM instead of RPM directly due to drifting of the measured values as the active testing time becomes longer.

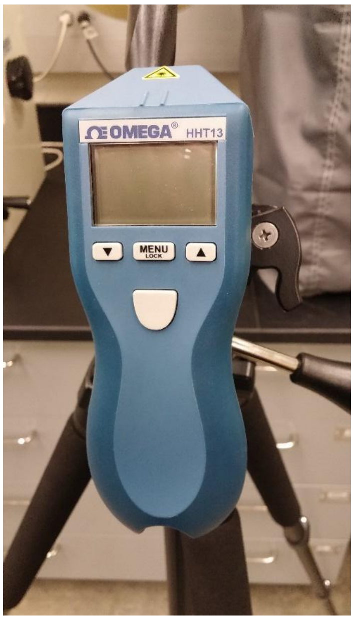

Figure 2. OMEGA HHT13 tachometer mounted onto a SLIK Pro 330DX tripod.

Reflective tape is applied to an Aluminum 71751-T74 dog-bonefatigue sample with a diameter of 0.375 inch. The tachometer measure the speed using a laser reflecting off of a surface. To reduce interferences caused by the polished aluminum surface To insure the tachometer only pick up the reflective tape using the laser and not the polished aluminum surface, the end where the reflective tape will be used is completely underneath the reflective tape completely enclosing that end of the sampleenclosed iswith regular blue masking tape as shown in Figure 3.

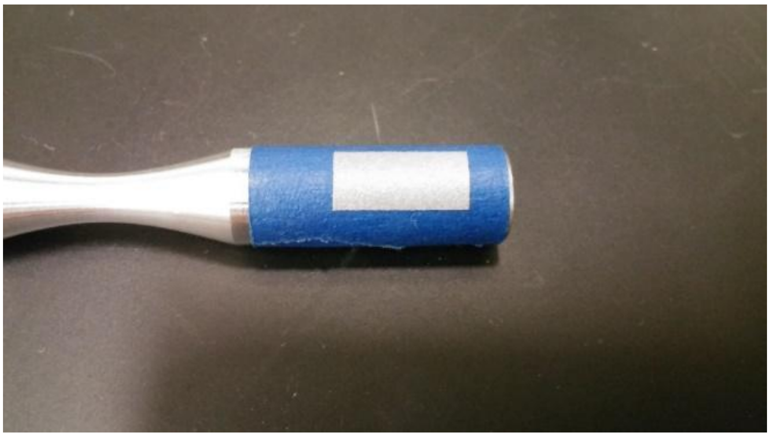

Figure 3. The primary reflective tape over blue masking tape that is used to prevent the tachometer from picking up unintended surface reflection from the polished aluminum surface.

Bending Moment Load Validation

To test the bending moment load settings of the fatigue machines, a Rosette strain gauge by Vishay Micro-Measurements was used. The Rosette strain gauge was applied onto a 0.5 inch diameter Aluminum 7175-T74 shaft with length of 4 inches following the standard procedures for the application of strain gauges. The strain gauge is then read by Vishay Precision Group’s Model P3 Strain Indicator and Recorder with each strain element for a total of 3, in a quarter bridge circuit, and with the correct Gage Factor provided by the strain gauge data card.

Principle strain is then calculated from the acquired Rosette strain gauge and the bending moment load will then be calculated from that principle strain. The bending moment load that was calculated using the strain data will then be compared to the expected bending moment load that was set on the machine.

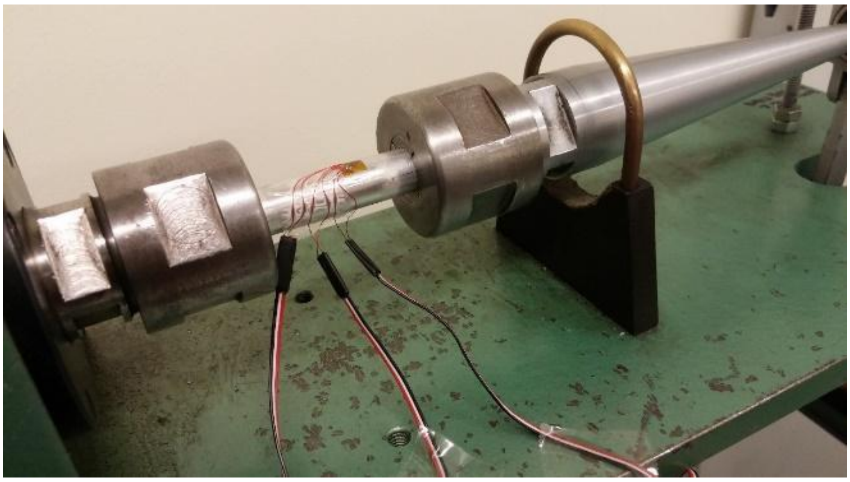

Figure 4. Rosette strain gauge is applied to an aluminum shaft and loaded into the machine. The machine stays off for the entire duration of the test with the gauge position to be at the top most to experience the highest strain due to bending.

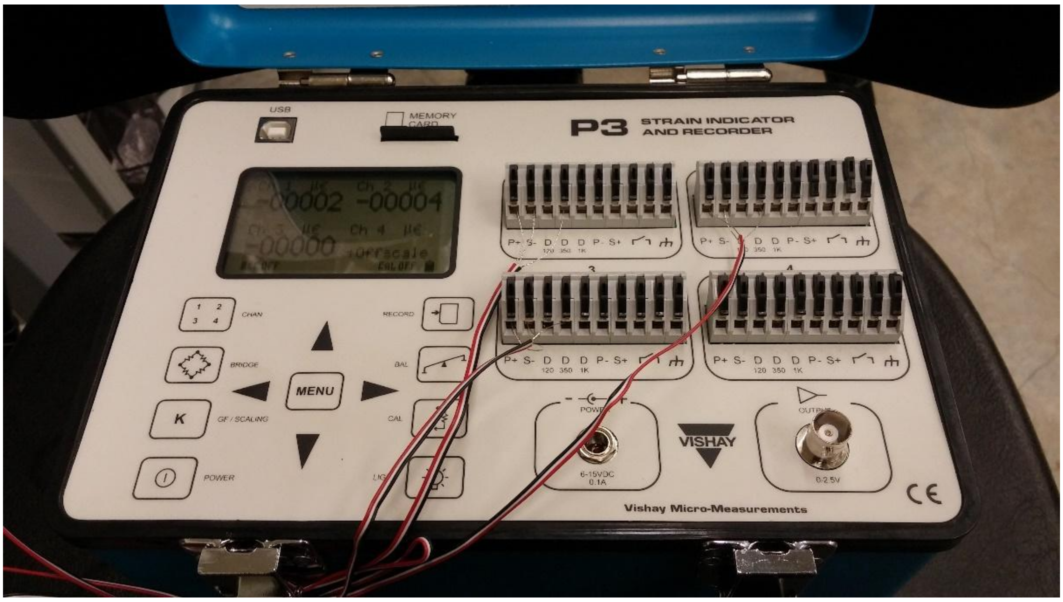

Figure 5. Vishay Precision Group's P3 Strain Indicator and Recorder. All strain gauges are in quarter bridge configuration.

The calculated bending moment load matches almost right on with the bending moment load set on the machines and errors are human errors caused by the analog nature of setting the bending moment load on the machines as it’s done mechanically by hand. Results for the top machine are shown below.

Table 1 Bending Loads

Bending Load (lb.-in)	Calculated Bending Load (lb.-in)
20	20.6215
40	40.2673
60	60.0320

Table 2 shows the initial results of low cycle fatigue failure. A specimen subjected the bending load 155 lb.-in (17.51265 N-m) failed after 9400 cycles:

Table 2 Fatigue Failure

Sample #	Diameter (in)	Length (in)	lb.-in	Cycles
1	0.306	3.6	155	9400

Its ultimate Tensile Strength is 520 MPa and the maximum bending stress on the surface is 390 MPa. We need to test all other specimens to obtain the S-N curve.
Figure 6 shows the cross section of the failed surface.

Figure 6. Failed surface of sample #1.

III. Experimental Results

The experiment ran starting with sample #7 and ending at sample #72. The samples' result is tabulated in Table 4 of Raw Data in Appendix A. The resulting S-N curve is shown in Figure 7.

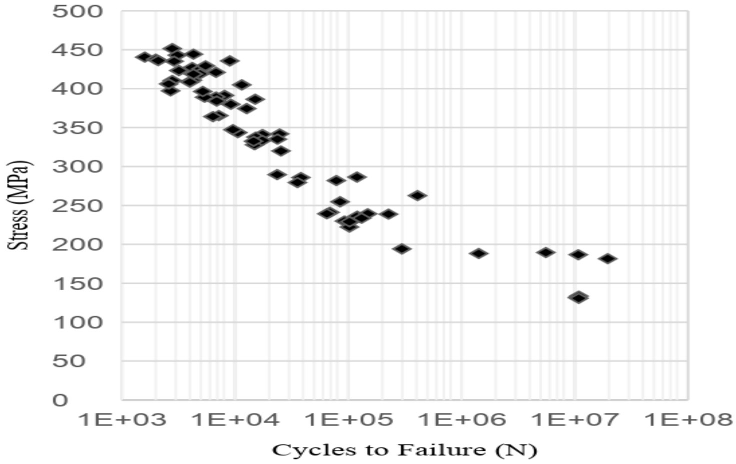

Figure 7. S-N curve of Aluminum 7075-T74.

Total data points at each bending load are:

Bending Load (lb.-in)	Total Samples
176 lb.-in (85% UTS)	10
166 lb.-in (80% UTS)	10
156 lb.-in (75% UTS)	10
135 lb.-in (65% UTS)	10
114 lb.-in (55% UTS)	7
145 lb.-in (45% UTS)	10
73 lb.-in (35% UTS)	5
52 lb.-in (25% UTS)	3

Table 3 Data Points at Each Bending Load

IV. Further Work

The Rosette strain gauge broke soon after the initial calibration at low bending load from 20 lb.-in to 60 lb.-in. Due to the length of time it would take before the new Rosette strain gauge would arrived, the experiment was continued. Although the set values of the bending load on the machine agrees closely with the actual applied bending load at 20, 40, and 60 lb.-in, the bending loads the samples are subjected in this experiment are at higher magnitudes and thereforeit is do not known the actual applied bending load the experimental samples are subjected to.

V. Conclusion

An S-N curve was plotted from the data collected for this experiment. Because at this moment there is limited access to information about the 7075-T74 material, the experimental results have not been compared with published values. However from the graph that was plotted, the S-N curve is following the expected trend of high stresses and low cycles and low stresses and high cycles. From the limited data, stress of under approximately 180 MPa start to experience runout in which 2 of 5 samples did not fail within 10 million cycles. This coincide with approximately 35% of UTS.

In addition, there are limited amount of samples to run the experiment to get a statistical significant result for the targeted stresses used for the experiments. Therefore more samples would be needed to get a statistically significant result for stresses lower than 80% UTS. Finally, the machine will need to be calibrated again through the entire range of the available bending moment load on the machine to verify how far off the actual applied bending moment compared to the bending moment settings on the machine.

References

[1]. Kocanda, S. (April 30, 1978). *Fatigue Failure of Metals (Fatigue and Fracture)*. Warsaw, Poland:Sijthoff & Noordhoff International.

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