Effects of Surface Finish on High Cycle Fatigue of Inconel 718

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Presented to the Faculty of the Materials Engineering Department
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In Partial Fulfillment
Of the Requirements for the Degree
Bachelor of Science, Materials Engineering.

by
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Abstract

Inconel 718 is a nickel-based superalloy and commonly used rocket engine material due to its excellent properties at elevated temperatures. Its fatigue life relies heavily on the surface roughness, as fatigue introduces and propagates cracks at the surface. Part standards set by Aerojet Rocketdyne typically necessitate surface roughness values from 64 to 125 Ra. However, surface topography and residual stresses incurred from the finishing process also affect the fatigue performance. The specific goal of the project is to perform a literature review and write experimental methods to determine how the surface roughness, topography, and residual stresses from turning, grit blasting, and polishing cumulatively affect mid-to-high cycle fatigue. Available literature shows that solution treated and aged, polished Inconel 718 reaches a high cycle fatigue regime within the stress amplitude range of 500 to 600 MPa. This range will be the starting point for producing useful S-N curves for the common finishing processes, polishing, turning, and grit blasting, used by Aerojet. Testing methods and analysis techniques will include surface roughness measurements using an Ambios XP1 stylus profilometer, scanning electron microscopy (SEM) imaging of surface topographies, fully reversed cantilever bending fatigue testing, and SEM fracture analysis. The safety issues addressed are relevant for fatigue testing, grit blasting, and using Kalling’s solution to etch Inconel 718 metallography samples.

Keywords

Nickel-based superalloys, Inconel 718, high-cycle fatigue, fatigue strength, fatigue testing, fully reversed cantilever beam bending, S-N curves, surface roughness, surface topography, profilometer, surface finish, polishing, turning, grit blasting, chemical milling, rocket engines, materials engineering
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1. Introduction

1.1 Company Background
Aerojet Rocketdyne is a global leader in the space and defense industries. They develop and manufacture liquid and solid-fueled propulsion systems, power systems, missiles, missile defense systems, and military weapons and equipment. They support space exploration as the primary supplier of main and upper-stage engines for rockets carrying astronauts, satellites, or space probes. In addition to launch systems, they also design and manufacture in-space power and propulsion systems for planetary probes and landers.¹

One of their largest contributions to the aerospace industry are their liquid-fueled rocket engines, including the RS68A, AR1, RL10, and RS-25 engines (Figure 1).

![Figure 1. RS-25 rocket engine before launch.¹](image)

RS-25 engines have powered 135 space shuttle flights, making them extremely reliable and well-tested. To launch NASA’s Space Launch System (SLS), four RS-25 engines are used, producing over two million pounds of thrust and allowing the system to reach low earth orbit in eight and a half minutes.¹

1.2 Inconel 718
1.2.1 Applications
Nickel-based superalloys are known for their high-strength at high temperatures and are commonly used in aerospace applications. Inconel 718, specifically, is used for its good workability, castability, and weldability. It is also corrosion resistant in extreme environments.

Aerojet Rocketdyne’s RS-25 engines are mostly comprised of Inconel 718. The engines undergo a staged combustion cycle that burns liquid hydrogen and oxygen, produces superheated water vapor, and results in operation temperatures between -423ºF and 6000ºF. The engine also undergoes pressures above 7000lbs/in². An efficient liquid hydrogen cooling system that runs
throughout the nozzle and main combustion chamber is used to bring temperatures down to a manageable range for Inconel 718.

1.2.2 Composition and Phases
Inconel 718 is composed of many elements, with the majority weight percent including nickel (Ni), chromium (Cr), iron (Fe), niobium (Nb), and molybdenum (Mo). Table I. Composition of Inconel 718 shows a typical composition for Inconel 718, however these weight percentages vary slightly, often to affect the phases that will precipitate during heat treatment.

<table>
<thead>
<tr>
<th>Composition (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
</tr>
<tr>
<td>IN718</td>
</tr>
</tbody>
</table>

Inconel 718’s matrix, $\delta$, is a face centered cubic (FCC) solid solution of Ni with Cr, Fe, and Mo. The precipitate phases in Inconel 718 are $\gamma'$, $\gamma''$, and $\delta$. $\gamma'$ and $\gamma''$ are fine scale precipitates that allow high strength at high temperatures. $\gamma'$ is an ordered FCC structure of Ni$_3$(Al,Ti), while $\gamma''$ is a metastable phase with a body centered tetragonal structure of Ni$_3$Nb (Figure 2).

Figure 2. Body centered tetragonal structure of $\gamma''$.

Using transmission electron microscopy, it can be seen that lighter elements, like aluminum, precipitate to $\gamma'$, while heavier elements, such as niobium, precipitate to form $\gamma''$. In addition, x-ray spectroscopy can display the location of these precipitated phases (Figure 3).
δ is the grain boundary precipitation phase that determines the grain size in the superalloy. Metastable γ''' transforms to δ at high temperatures (1290-1830°C), forming thin plates and elongating into the stable phase of orthorhombic $\text{Ni}_3\text{Nb}$. Boron, carbon, and zirconium, whose atomic radii are much smaller than that of Ni, precipitate to the grain boundary.

1.2.3 Heat Treating
Most Inconel 718 is solution heat treated and aged in order to yield the best properties. The solution treatment, which is also called solution annealing, involves heating the Inconel 718 above the δ solvus temperature to cause the phases to enter a solid solution. The Inconel is then cooled rapidly using water or oil in order to lock in γ' and γ''' phases. Next, Inconel 718 is aged at temperatures below the δ solvus temperature in order to promote controlled growth of these solid solution phases. According to the time-temperature-transformation diagram of Inconel 718, aging around 1470°F for 8-10 hours, cooling to around 1290°F and holding for another 8-10 hours will yield the best growth of γ' and γ''' phases (Figure 4).
There are two main solution treat and age treatments used in aerospace applications for Inconel 718. The first treatment involves solution treating above the $\delta$ solvus temperature at 1775°F for one hour before quenching in oil. Then, the Inconel 718 is aged at 1325°F for 8 hours, furnace cooled to 1150°F, and held at 1150°F until a total precipitation heat treatment time of 18 hours is reached. Then, the samples are air cooled. This heat treatment increases the tensile strength of the alloy and conforms to AMS 5662.

The second common Inconel 718 heat treatment results in increased creep resistance, which is resistance to deformation from prolonged loads, often at high temperatures. The Inconel 718 is solution heat treated at 1900°F for 1 hour, then oil quenched. The Inconel is then aged at 1400°F for 10 hours, furnace cooled to 1200°F, and held at 1200°F until a total precipitation age heat treatment time of 20 hours is reached. The samples are then air cooled. This heat treatment conforms to AMS 5664 and results in a microstructure with an increased concentration of $\gamma'$ (Figure 5).
1.3 Fatigue Background

1.3.1 Fatigue

Fatigue is the process of gradual plastic deformation when subjecting a material to forces that produce fluctuating stresses and strains at one or multiple points which may lead to cracks or complete fracture after a sufficient number of cycles.\textsuperscript{11} Fatigue testing is important for understanding how a material responds to cyclic loading, as the deformation is often unrecognized until catastrophic failure occurs. Low cycle fatigue testing is generally done with loads higher than the material yield stress and the resulting cycles to failure are usually less than $10^4$ cycles. High cycle fatigue is defined as having low stress amplitude, below the material’s yield strength, and surviving more than $10^4$ cycles.\textsuperscript{12}

1.3.2 Standard Data: S-N Curves

There is significant data on the fatigue behavior and S-N curves for polished Inconel 718. The literature fatigue data for solution treated and aged Inconel 718 conforming to AMS 5662 displays the high cycle regime of fatigue testing, beginning around $10^5$ cycles (Figure 6).

![Figure 6. Best fit S-N curve for fully reversed bending (R=-1) for aged Inconel 718 at room temperature.\textsuperscript{13}](image)

In addition, there is data for solution treated and aged Inconel 718 conforming to AMS 5664, however, this data is not as abundant as fatigue data for Inconel 718 conforming to AMS 5662. An upper and lower bound of fatigue data yields the average S-N curve based on the data collected (Figure 7).
Most stress amplitudes tested were within a range of 450MPa to 700MPa. Below 500MPa a significant number of samples did not fail after reaching $10^7$ cycles or more. The high cycle fatigue range for polished Inconel 718 is reached around 500 to 600MPa.

1.3.3 Variables that Affect Fatigue
Surface roughness is characterized by deviations and irregularities from the theoretically perfect surface of the material. These irregularities range from peaks and valleys to dissimilarities in the interatomic distances and order. It is impossible to machine or polish a surface that produces a molecularly flat surface. A common method of measuring surface roughness is using $R_a$. $R_a$ is the average of the absolute values of the vertical deviation from the reference line and is shown in Figure 8 as the mean line.

Figure 7. Fatigue data of Inconel 718 tested at room temperature and $R= -1$ loading.

Figure 8. Schematic of an example surface roughness and how $R_a$ is calculated.
Different instruments are used to measure the surface roughness of a material, such as a mechanical stylus and sensor mechanism that moves over the surface of a material. Another method that produces a 3D model of a surface is a 3D interferometer, which produces a model of the surface using electromagnetic waves to detect irregularities and roughness.

Aerojet Rocketdyne utilizes multiple machining operations when finishing their workpieces, which yield different surface roughness values that need to be up to specifications. Typically, parts are within the range of 64 to 125 Ra. Most parts fall closer to the 125 Ra value but cannot go over in order to meet specifications (Table II).

<table>
<thead>
<tr>
<th>Finishing Method</th>
<th>Standard Roughness Range (Ra)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Limit: Special Cases</td>
</tr>
<tr>
<td>Turned (Lathe)</td>
<td>64</td>
</tr>
<tr>
<td>Grit Blasted (Silicon Carbide)</td>
<td>64</td>
</tr>
<tr>
<td>Fully Polished</td>
<td>10</td>
</tr>
</tbody>
</table>

In addition to roughness, surface topography can affect a material’s fatigue life. For example, Figure 9 shows two theoretical sample surfaces with the same roughness value, but distinctively different topography and likely differing fatigue performance.

Residual stresses will also have a distinct effect on a material’s fatigue life but is difficult to measure independently. Shot peening is an example of a process that introduces residual stresses by deforming the surface and usually results in an increase in fatigue performance.

1.4 Fatigue Testing
1.4.1 Fatigue Machines
Cantilever bending occurs when one end of the material sample is fixed in place and the other end is subjected to loading cycles. The test apparatus rotates the sample to apply load equally in both directions (Figure 10).
Another type of fatigue testing is ultrasonic fatigue testing. Ultrasonic fatigue testing involves using longitudinal vibrations at frequencies between 15 and 25 kHz. This loads the specimen cyclically and allows for shortened test times since the loading frequency is so high. Figure 11 displays a schematic for an ultrasonic fatigue test machine, in which an amplifying horn is used to generate the longitudinal waves necessary to load the specimen.

Different strain gauges and measurement tools measure the slightest change in dimensions of the sample from the original. The tester will stop when it detects crack initiation. The cooling air is necessary to run the tests at high speeds and prevent sample heating.

1.4.2 Loading Conditions
The experimental loading condition of the sample is often expressed using the ratio of minimum and maximum stress, \( R = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \). Therefore, when the sample is placed under fully reversed cyclic loading conditions, \( R = -1 \). The stress placed on the sample in one direction is equal to the stress on the sample in the opposite direction, maintaining a mean stress of zero (Figure 12).
Figure 12. Stress function for fully reversed cyclic loading condition \( (R = -1) \).\(^{12}\)

\( R = -1 \) is the most extreme fatigue loading condition. An \( R = 0 \) condition would load the sample with unidirectional stress.\(^{19}\) The sample would be loaded in one direction to \( \sigma_{\text{max}} \), then unloaded. Additional \( R \) loading conditions are seen in Figure 13 and Figure 14.

Figure 13. \( R = 0.5 \) fatigue loading condition and the direction of load on a fatigue sample.\(^{19}\)

Figure 14. \( R = -0.5 \) fatigue loading condition and the direction of load on a fatigue sample.\(^{19}\)

Depending on the application, the loading condition can be chosen to mimic the true loads experienced by the material while in use. However, \( R = -1 \) is often chosen, because it is the most extreme loading case and the data is more conservative.
1.4.3 Loading Modes
Furthermore, the load can be bending, axial, or torsional. Figure 15 shows a comparison of the loading methods cycles to failure with relative stress amplitudes.

![Figure 15. Relative stress amplitude versus number of cycles to failure for bending, axial, and torsion fatigue loading.](image)

1.4.4 Frequency
In addition, the frequency used in the experimental method affects the number of initiation sites and the overall fatigue life of nickel-base superalloy samples. Comparisons between an ultrasonic fatigue testing method using a frequency of 20 kHz and rotary bending fatigue testing at a frequency of 52.5 Hz at room temperature showed that ultrasonic testing resulted in increased fatigue life. At lower frequencies cracks initiated from multiple source, whereas samples tested ultrasonically usually initiated from a single subsurface inclusion.

In standard fatigue testing, each sample is tested at a different stress amplitude until failure occurs. The resulting data will form an S-N curve, which plots stress amplitude versus cycles to failure.

1.5 Finishing Processes
1.5.1 Polishing
Polished Inconel 718 is ideal, as the surface roughness measures between 10 to 32 Rₐ and increases fatigue strength considerably. It is widely accepted that fatigue cracks initiate at the surface of the materials, so fatigue strength is sensitive to any surface defects.

1.5.2 Turning
Turning is performed by rotating the workpiece as a cutting tool moves along the surface of the workpiece, as seen in (Figure 16).
In turning, the cutting tool can be used parallel, perpendicular, or at an angle to the workpiece, which makes it versatile in turning, facing, parting, drilling, or boring. Workpieces generally have a circular cross section and are secured in the lathe using a 3-jaw chuck.

Surface roughness can be controlled via controlling the feed rate of the cutting tool. The slower the rate, the better the finish on the piece. Equations can be used to approximate surface roughness based on the type of tool used in the turning process and the feed rate. Equation 1 determines the maximum surface roughness \( h_{\text{max}} \) when turning with a sharp tool, where \( s_o \) is the feed rate (mm/rev), \( \phi \) is the principal cutting edge angle, and \( \phi_1 \) is the auxiliary cutting edge angle of the cutting tool.

\[
h_{\text{max}} = \frac{s_o}{\cot \phi + \cot \phi_1}
\]

1.5.3 Grit Blasting
During grit blasting, an abrasive material is shot at a high pressure at the surface of a workpiece using blasters powered with compressed air (Figure 17).
Grit blasting is used as a finishing process or to clean surfaces of debris. Possible abrasive materials include sand, silicon carbide, and alumina, which are chosen based on diameter, strength, hardness, and density in order to fit the needs of the machining process. Silicon carbide is one of the hardest grit blasting media and it can be re-used many times. These properties allow it to have a fast cutting action and shorten the blast time compared to other grit media.\textsuperscript{26}

1.5.4 Chemical Milling

Chemical milling involves using etching chemicals in order to remove material from a work piece. These etchant chemicals are kept in temperature-controlled tanks as materials are immersed in them to achieve a desired shape or form.

Chemical milling takes place in a series of five steps. First, the workpiece is cleaned in order to rid the surface of any contaminants such as grease, oils, markings, and oxidation. Without cleaning the surface of the workpiece, the chemical milling process will produce low-quality parts. Solvents, alkaline, or oxidizing solutions are used to clean the surface of any contaminants. Next, a protective coating called a masking material is applied to the surface of the workpiece in order to protect the areas that will not be etched in the chemical milling process. This masking material is usually some sort of neoprene elastomer. Scribing then takes place in order to outline the areas to be chemical milled. After the area to be milled is defined, the workpiece is immersed in the chemical etching bath in order to remove the desired amount of material (Figure 18). The amount of material removed depends on the time the workpiece is immersed in the etchant, type of etchant, and material of the workpiece. For Inconel 718, ferric chloride is usually used. After the desired amount of material is removed, demasking takes place in order to remove excess masking material and etchant.\textsuperscript{27}

Figure 18: A workpiece being submerged into a chemical etchant bath.\textsuperscript{28}

Chemical milling is used in the aerospace industry in order to remove small layers of materials found on aircraft components, extruded airframe parts, and missile panels. It is also used in the semiconductor industries as well as to produce circuit boards and microelectronic systems.\textsuperscript{27}
Chemical milling can affect the surface roughness and topography of a metal in a variety of ways. Chemical milling usually produces pieces with a low surface roughness value; however, this surface roughness can be altered by the parameters of the chemical milling. For example, etching time, chemical temperature, and chemical concentration can all affect the surface roughness of the piece. The longer the etch time, the higher the concentration of chemical, and the higher the temperature results in a higher surface roughness.

If the chemical concentration increases, the surface roughness also increases due to the increase in the number of molecules in the chemical (Figure 19). This increases in number of molecules increases etch rate, which increases the surface roughness.

![Graph](image)

**Figure 19**: As the etchant concentration increases, so does the surface roughness of the Inconel 718.

The etching time begins to level off after a certain amount of time, but as it reaches this cut-off time, the surface roughness increases with an increase in etching time (Figure 20). Since the dissolution of material takes time, the time it takes for the diffusion reaction to take place can dictate the surface roughness. Once the cut-off time is reached, however, the diffusion reaction between the chemical and the surface of the piece becomes stable.
An increase in temperature increases the kinetic energy in the system, resulting in more bond breaking and more material removal. A higher temperature will result in a higher surface roughness (Figure 21).

In addition, grain size can also affect the surface roughness during chemical milling. Since grain boundaries have higher energy bonds as compared to grain surface, they etch and dissolve easier than the grain surface. The larger the grain size, the stronger these bonds are and less grain boundary area there are to etch easier.

1.6 Summary
The fatigue life of Inconel 718 relies heavily on the surface roughness, as fatigue is known to induce and propagate cracks at the surface. The minimizing of preexisting surface flaws by polishing maximizes the fatigue performance. However, other finishing processes are used to repair mis-machined parts. The standards set by Aerojet only take into account surface roughness for compliance of parts, however surface topography and residual stresses incurred from the
finishing process also affect the fatigue performance. Furthermore, mid-to-high cycle portions of the fatigue curve are most relevant to ensuring safety and performance compliance for an RS-25 engine. During rocket takeoff, the controlled combustions, thermal expansion, and vibrations a rocket engine endures is estimated to near the range of $10^6$ cycles before being released from the rocket.

1.7 Safety
When using the fatigue machine, ensure that loose articles of clothing, jewelry, or long hair are out of way and not in danger of being caught in the machine. Proper personal protective equipment (PPE) should be worn, including long pants, closed-toes shoes, and safety glasses. Standard Operating Procedures (SOPs) should be followed when using the fatigue machine.

Grit blasting requires a special grit blasting cabinet with protective gloves built in to handle sample safely. In addition, a safety mask should be used to prevent particulates from being inhaled. The type of mask needed is determined by the grit medium and grit size.

When using chemical etchants for metallography, one must be sure to wear proper PPE and follow lab safety guidelines in order to ensure the safety of oneself and others in the lab. Consult the glove selection chart when deciding the type of gloves one needs to wear when handling certain chemicals. Many chemical etchants can be dangerous if used incorrectly or mixed with other chemicals, so one should always know how the chemicals will behave in different situations. When storing chemical etchants, be sure to label and date the etchant bottles and store them in proper places. Always dispose of unused etchant and waste materials in the proper waste containers.

2. Experimental Procedure
Ten fatigue samples will be obtained for each machining finish, for a total of 30 samples. The control group will be polished Inconel 718. Turned and grit blasted Inconel 718 samples will also be tested to compare the fatigue failure. The samples will be obtained as rods of Inconel conforming to AMS5662 with the composition shown in Table I.

The rods will be cut to the size of the fatigue sample dimensions. These pieces will be solution heat treated and aged according to AMS5662. The rods will be heated to 1325°F ± 15°F for 8 hours, furnace cooled to 1150°F ± 15° for 9 hours, then cooled in air. Because the rods are heat treated before they are machined, heat treating in air is acceptable, as the outer layers of Inconel 718 will be machined away in later steps. After heat treating, one rod will be hardness tested and the microstructure will be observed to ensure minimum post-heat treatment AMS5662 properties are met. Then, the rods will be sent to an outside source for machining. The dimensions of the fatigue samples are shown in Figure 22.
Figure 22: Engineering drawing of rotating bending fatigue sample.

The samples will be machined to these specifications, with 10 samples being finished with turning, 10 finished with grit blasting, and the last 10 samples fully polished.

2.1 Machine Finish
The purpose of this project is to determine the reliability of parts finished by polishing, turning, and grit blasting on the high end of Aerojet’s surface roughness specifications. Therefore, the target Ra value for all machining finishes will be 120 Ra, which is close to the upper limit of surface roughness specifications.

2.1.1 Turning
For the turned samples, surface roughness can be controlled via controlling the feed rate of the cutting tool. The slower the rate, the better the finish on the piece. Equation 1 can be used to approximate surface roughness based on the type of tool used in the turning process and the feed rate. If these calculations cannot be implemented, we will confer with the machinist to determine the feed rate of the finishing pass. Multiple expendable samples will be roughness tested to determine the ideal machining conditions for Ra values closest to 120 Ra.

2.1.2 Grit Blasting
For grit blasting the samples, either alumina or silicon carbide will be used, depending on what is available.
Table III relates the grit finish to the estimate surface roughness values.

Table III. Grit Finish and Converted Surface Roughness Values

<table>
<thead>
<tr>
<th>Grit Finish</th>
<th>RMS (Micro-inch)</th>
<th>RMS (Micron)</th>
<th>Ra (Micro-inch)</th>
<th>Ra (Micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>160</td>
<td>4.06</td>
<td>142</td>
<td>3.61</td>
</tr>
<tr>
<td>60</td>
<td>98</td>
<td>2.49</td>
<td>87</td>
<td>2.21</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>2.03</td>
<td>71</td>
<td>1.8</td>
</tr>
<tr>
<td>120</td>
<td>58</td>
<td>1.47</td>
<td>52</td>
<td>1.32</td>
</tr>
<tr>
<td>150</td>
<td>47</td>
<td>1.2</td>
<td>42</td>
<td>1.06</td>
</tr>
<tr>
<td>USDA Bead Blast</td>
<td>47</td>
<td>1.2</td>
<td>42</td>
<td>1.06</td>
</tr>
<tr>
<td>180</td>
<td>34</td>
<td>0.86</td>
<td>30</td>
<td>0.76</td>
</tr>
<tr>
<td>220</td>
<td>21</td>
<td>0.53</td>
<td>19</td>
<td>0.48</td>
</tr>
<tr>
<td>240</td>
<td>17</td>
<td>0.43</td>
<td>15</td>
<td>0.38</td>
</tr>
<tr>
<td>320</td>
<td>14</td>
<td>0.36</td>
<td>12</td>
<td>0.3</td>
</tr>
<tr>
<td>400</td>
<td>10</td>
<td>0.25</td>
<td>9</td>
<td>0.23</td>
</tr>
<tr>
<td>Mirror</td>
<td>5</td>
<td>0.13</td>
<td>4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Therefore, in order to achieve a surface roughness between 64-125 Ra to conform with Aerojet Rocketdyne standards, the planned grit size of the alumina or silicon carbide will be either 60 or 80 mesh size grit. Expendable Inconel samples will be used to test multiple grit sizes to ensure the closest Ra values to 120 Ra.

2.1.3 Fully Polished

In order to fully polish the last 10 samples, the following process was used by a previous senior project group with similarly shaped fatigue samples.

1. Ensure the sample is clean of debris and grime.

2. Use a small strip of 600-grit abrasive paper to grind the surface of the sample. Grind along the length of the sample until the entire region of reduced area has been ground evenly.

3. Clean the sample using soap and water. Thoroughly dry the sample.

4. Fasten the sample securely into the rotating bending fatigue (RBF) machine. Turn the machine on to a frequency between 20-30 Hz.

5. Use a small strip of dampened 800-grit abrasive paper to polish the surface of the hourglass-shaped sample circumferentially as the sample rotates in the machine. Polish for 60-90 seconds or until the sample has a smooth, even surface finish.

6. Remove the sample from the RBF machine.
7. Repeat steps 3 and 4 to clean the sample and replace it in the RBF machine.

8. Use a small strip of dampened 1200-grit abrasive paper to polish the surface of the hourglass shaped sample circumferentially as the sample rotates in the machine. Polish for 60-90 seconds or until the sample has a smooth, even surface finish.

9. Remove the sample from the RBF machine.

10. Repeat steps 3 and 4 to clean the sample and replace it in the RBF machine.

11. Use a soft polishing pad with 1µm polycrystalline diamond abrasive to perform a circumferential final polish on the sample. Polish for 1-2 minutes or until the sample has a smooth, mirror-like surface finish. Clean the sample with a soft, damp cloth.

12. Visually inspect the surface of the sample for deep scratches or other visible flaws. If in good condition, proceed with sample testing. If a flaw is identified, acquire a new sample and repeat this procedure.

2.2 Fatigue Testing
After the samples have been properly finished, surface roughness measurements will be taken using an Ambios XP1 stylus profilometer. Then, the samples will be tested with fully reversed loading, cantilever bending in the high cycle regime. The fatigue tester will be run until it detects fracture of the samples. According to literature, stress amplitudes between 500 and 600 MPa are sufficient for testing in the high cycle fatigue regime for Inconel 718. This will be the starting range for testing the samples, and additional stress amplitudes will be chosen to produce the most useful high-cycle S-N curve.

3. Results
Since polishing was used as a baseline control group for the fatigue samples, the polishing method had to be tested in order to see what surface roughness the method would yield. Using flat Inconel 718 samples, a hybrid of the polishing method was used, which involved polishing with 600, 800, and 1200 grit papers. After using the grit papers, a 1-micron polishing pad with polycrystalline dialube was used to final polish the sample. Using a stylus profilometer, surface roughness measurements were taken, yielding the peaks and valleys that characterized the surface, with a scan length of 5 mm (Figure 23). The red line indicates the Ra value.
Figure 23: Ra graph of a flat Inconel 718 sample, with an Ra value of -1.36.

With an Ra value of -1.36, the polishing method yielded a surface roughness value well below the Aerojet roughness standard of 32 Ra. This test confirmed that our polishing method would be more than effective at fulfilling our polishing surface roughness target.

Unfortunately, the COVID-19 pandemic that began in March of 2020, the major experimental portion of this project could not be completed.
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