Hello – My name is Levi Lentz and one of my roles in this project was to do the analysis on the material after we had selected a material to test. Because of the complex loading, this involved a multitude of steps including finding the internal pressure, fatigue life, thermal stress and crack length.

Next to the thermal analysis of this project, the hardest part was finding the internal pressure that the cylinder felt due to the combustion of the gas. In order to do this, we used two methods to corroborate the results. The first was to use the acceleration vector, treating the piston assembly as a closed vector and differentiating twice to get the acceleration. The other method was to use the ideal gas model just after combustion, with the pressure varying only with position. Both of these methods came up with an internal pressure of about 3MPa, within 5% of each other.

This graph shows the internal pressure of the system. Please note, this is just a model, as the intake of the vapor and the combustion of the vapor would create two points that would be discontinuous. This internal pressure will be the driver of much of the material consideration.

What we first have to note is that the hoop stress is going to be the true limiting factor of the material. The hoop stress is going to be a stress internally in the cylinder walls. I was going to put up its graph, but it will look identical, just it will be approximately 10x as large, yielding a maximum stress of 23MPa and a minimum of 2MPa.

As you saw in the previous graph, the load on our cylinder will be cyclic in nature. This creates a problem when it comes to the Wohler curve, or our so-called S-N curve. Ceramics in general do not display a very S-N curve, and almost none of them have an endurance limit. Silicon Nitride was no different. We had to use data obtained from S-N tests on Silicon Nitride at 1000C. From this data we obtained the following relationship that models the fatigue life. This is graphed to our right. As you can see, there is no defined fatigue limit. This leads to the following life under the hoop-stress loading. However, each engine cycle contains two such loadings so our effective life is half of that. From the number of cycles per race (given here) we have a huge factor of safety.

The other limiting factor will be the thermal expansion. We used super position to find this stress (where the thermal strain was offset by a compression stress) and found it to be 481MPa due to the large modulus of elasticity for Silicon Nitride. This stress is the driving factor behind the maximum crack length. From this stress and the Irwin Modification to the Griffith equation, we get that our edge crack length of .05mm. While this is a short length, because of the manufacturing process, it is possible to make a part with this tolerance. Please note that this is length is only on the cylinder sleeve, the piston can have a much higher crack length and still withstand the load.

DESIGN CONSIDERATIONS

We have shown that Silicon Nitride can work as a cylinder sleeve and piston in an F1 engine as well as increase the overall efficiency.

In the past, the trend has been for the FIA (Regulatory agency for the F1 races) has been to eliminate the non-ferrous materials, therefore it would be beneficial to find an aluminum-type material to replace the silicon nitride. The benefits it would need to be a reliable alternative would be: ease of manufacture as well as similar thermal-properties. Something like this was not able to be found.