Presentation Script V1

Good morning. My name is Charlie Nitschelm and my talk will be on Inconel 625 in tension and compression under the mentorship of Dr. Steven Mates.

As you heard from the last talk, Inconel 625 is a super-alloy made of many different elements, but primarily nickel. Its usefulness in various industries, like aerospace and automotive, make it an extremely important material to understand. It is known to have a very high strength to weight ratio, it is oxidation and corrosion resistant and great in high pressure and temperature environments. This material is great in certain parts of rocket engines where it needs to not only survive its environment for one flight, but be able to be reused again and again like we see a lot of aerospace companies doing.

For our purposes, we are working to better design a process to manufacture a Lamina insert for a heat exchanger. There are huge amounts of waste heat everyday around the world, whether it be coal or oil, heat exchangers would enable our waste heat to be converted back into electricity. Waste heat generators operate at high temperatures and may encounter corrosive liquids, so Inconel 625 is a perfect choice of material for this challenging environment

This lamina insert is very thin, around .5mm thick. Its traditional methods to manufacture now are time consuming, expensive and a lot of material is wasted. Our goal in this research is to design a new manufacturing process that will cut down on costs, limit material waste, and be able to achieve the same tolerances we get with the other methods.

In this Dynamic forming process, the material will be deformed very quickly, causing very high strain rates and large temperature increases due to adiabatic heating. That is the reason we will need to test this material at its limits of strain rate and heating times to understand how this material will behave under this process.

Inconel 625 is a single phase, face center cubic metal, and you can see a typical microstructure to the right. This clearly shows that there is no texture to the material yet, meaning it has no specific orientation it favors. We say that the grains in this material are equiaxed. But, once a material is rolled into sheet metal, the material we will be testing on and what the Lamina insert will be manufactured from, it begins to show a lot of texture, stretching grains into oblong shapes and changing their orientations to favor a specific direction. This can result in a material that shows different strength depending on which direction you test it.

That is why we will be testing Inconel 625 in various direction to fully understand how the material behaves under the influence of its new texture. From the new dynamic forming process, we will also have to understand how the material behaves at low and high strain rates. To test these conditions, we are using a servo hydraulic test machine so we can achieve the low strain rates of 10 to the -4 and 10 to the -1/s. To achieve the strain rates closer to 1000/s, we will be using a Kolsky bar.

The kolsky bar is a great tool to understand how large strain rates affect the mechanical behavior of a material, but it also has its limitations that need to be accounted for. There is a standard test method for testing metals in tension, and in that standard it specifies how the test specimen must be designed. Although we follow a few guidelines, like using the entire thickness of our .5mm sheet of Inconel 625, we fall once we get to the recommended gage length. The ASTM E8 standard requires a 32mm gage length, while we were forces to design it to only 7mm. This is because the Kolsky bar can only stretch the sample a certain length during the time of the test, and we need to achieve a strain that would get us close to fracture. From that, we do not follow the guidelines of E8, but it does allow the test to occur so we can discover useful data on its behavior at these high strains.

Pictured to the right is the Kolsky bar, designed for strain rate around 1000/s, which is crucial to understand for the applications that see these strain rates, like dynamic forming, high speed machining, and automobile crashes.

The Kolsky bar functions by introducing a striker bar that hits the incident bar, pushing a compression wave towards the sample, and producing a reflected and transmitted pulse. These pulses are then collected by the strain gages on each bar which is then able to graph a stress strain curve of the experiment at the strain rate experienced. These pulses move at the speed of sound in steel, roughly 5000m/s. Although this example was for compression, which we will see in a few minutes, tension is can also be accomplished by inverting the striker bar impact direction.

Another, more modern, way of collecting our data during the tension tests is using 3d Digital image correlation. This setup requires two high speed cameras looking at the specimen during the test. The specimen is painted at the gage section with a white background and black speckles. The cameras are then able to track these speckles as the gage deforms, producing the shape displacement and strain locally for each frame captured during the test.

Here is a movie from one of our tensile tests, showing the movement of the specimen as the tensile waves passes through. You can also clearly see the speckled paint on the specimen, so the cameras can produce a graph detailing its deformation through time.

This graph details the results from the high strain tests at the various orientations. There is definitely some scatter, including an error in one of our rolling direction experiments, but you can begin to see a trend in how the material behaves. If I bring up the mean values of each direction, you see that the rolling direction, the orientation that moves with the microstructure, shows less strength throughout the stress strain curve.

Pictured to the right is the servo hydraulic testing machine that was used for our slower strain rates. It is also important to understand how Inconel 625 behaves under an increasing load over a longer period of time. Because the lamina being deformed via the dynamic forming operation is experiencing many strain rates simultaneously (including the maximum one) we need to understand how this material behaves over a wide range of strain rates

These data here were gathered over a time interval of around 2 hours due to such a low strain rate of 8.7 \* 10^-4/s. With these curves, it shows that each orientation behaves almost identically with each other, meaning the texture and orientation at these low strain rates do not play a crucial role in its mechanical behavior in tension.

You can see this more clearly when the averages are displayed for each specific orientation.

Here is a video of what the DIC records during the test. As the test progress’, the strain near fracture increases until fracture occurs. The speckles painting on the specimen allows these cameras to make the measurements.

One point that is extremely important to verify is if our tension specimen yields vastly different results due to its different design compared to the E8 standard specimen. This graph illustrates this exactly. The red lines is the data collected at the University of new Hampshire using an ASTM E8 specimen on an MTS, where the green shows our tension specimen data on the MTS. Although there is a slight disagreement at the later strains, these data are very similar.

We see these same results in each orientation, like here in the transverse direction.

By testing multiple strain rates, we are able to see how strain rate effects a certain orientations mechanical behavior clearly. Apart from the high strain rate outlier here, you can begin to see trends…

These averages clearly show how each strain rate can affect the mechanical behavior of the material including how much strain it can take before fracture.

Another important effect the material will undergo during dynamic forming is temperature change. Currently there is no ASTM standard for Kolsky bar compression testing. We chose to use compression specimens for our heating data because it is far easier to heat compression specimens then tension specimens, and the graph on the bottom right shows that choosing the compression specimens for temperature testing did not significantly affect its stress strain curve, allowing us to trust the data we get from the tests.

As a kolsky bar outfitted with pulse heating, the mechanics is nearly the same, except prior to mechanical impact, a battery banks supplies a large amperage to the specimen, allowing it to be heated to nearly 1000 C in just a couple of seconds. The current is then cutoff and is immediately followed with mechanical deformation.

This busy graph show how the mechanical strength drops as temperature increases, a well-known trend in materials science. All the data we gathered, including strain rate and temperature effects, will allow us to calibrate a model for Inconel 625 that is suitable to simulate the dynamic forming process shown earlier.

The Johnson-Cook model is a well-known model that captures strain rate and temperature sensitivity of mechanical strength, and it works well for many metals.

To the parameter values needed for Johnson-Cook model, an equation that will allow us to correctly design the dynamic forming process with the right parameters, including thermal softening, rate sensitivity and yield and hardening parameters.

Overall, during this Summer we were able to measure the mechanical behavior of Inconel 625 at various strain rates and orientation to its rolling texture and test the thermal softening of the material in compression. These data will then be able to be fit to the Johnson-Cook flow stress model that can then accurately simulate the dynamic forming of the lamina component ins a heat exchanger. Thank you.

Questions?