Split mandrel coldworking

Paul Shemeta

Split mandrel coldworking is a process for creating compressive stress around the edges of a hole – typically bolt holes and open fuel flow holes in aircraft structures. This locked in compressive stress reduces the stress riser effect at the edge of a hole, increasing fatigue life typically by a factor of 3 to 5 times.

Split mandrel coldworking can be automated, unlike the more common sleeve coldwork process.

In this talk, I'd like to give you a "gut feel" of what is going on in the coldwork process in general. There are a lot of misconceptions of what the process accomplishes and what the issues are. Not surprising since you can't buy a book or take a college class on the subject.

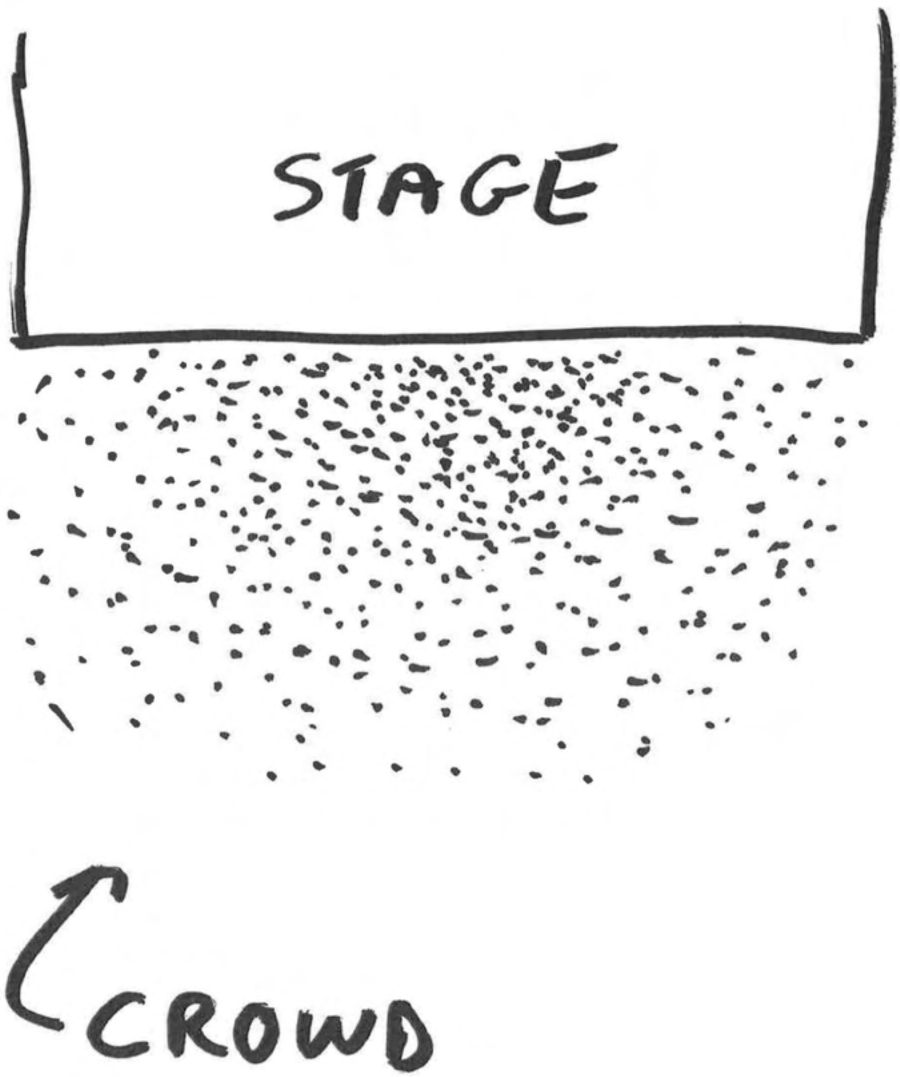
Some history on the coldwork process – the F-18 aircraft, as far as I know, was the first aircraft with extensive use of coldworking for structural holes. Most aerospace primes, subcontractors and MRO operators around the world have adopted a system of tools to accomplish coldworking that was formalized by Joe Phillips of the Boeing company in the 1970's.

The basic plot of coldworking is to somehow force a tool larger than a hole thru the hole. This causes the material at the edge of the hole to plastically deform in tension, the hole is now bigger than it was before the mandrel passed thru it.

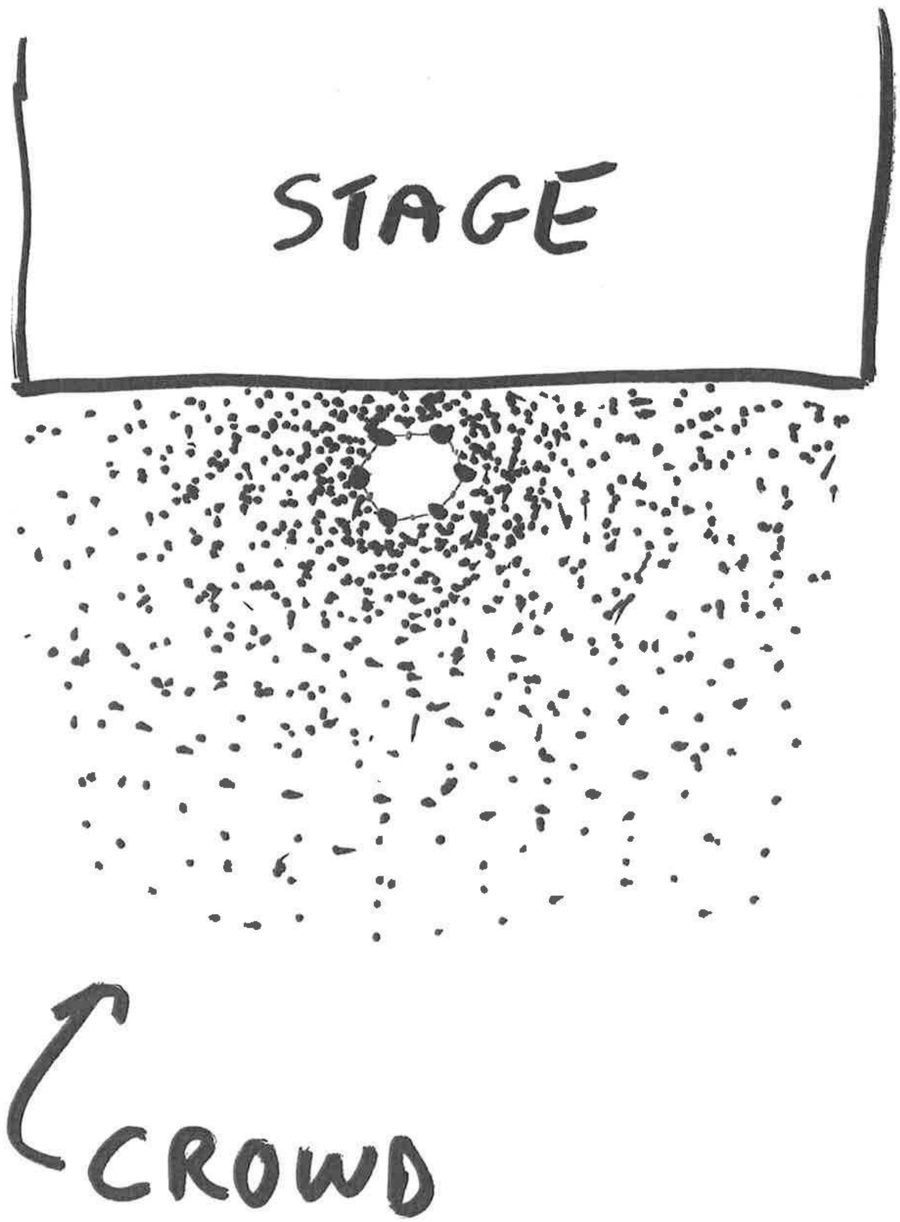
Material distant from the hole is also stressed during the coldwork process, but only in its elastic range – so it would like to return to its original shape. In returning to its original shape, it pushes on the material that has been permanently deformed at the edge of the hole, putting it into a state of high compressive stress.

Thus, the most basic fact of coldworking is – you need ductile material! If you can't imagine bending a wire made out of the material you would like to coldwork, don't even think about coldworking it. Don't try it on carbon fiber or a hole in a glass window.

To better understand what coldworking is doing, think about being in a tightly packed crowd at Mardi Gras or at a concert right in front of the stage.

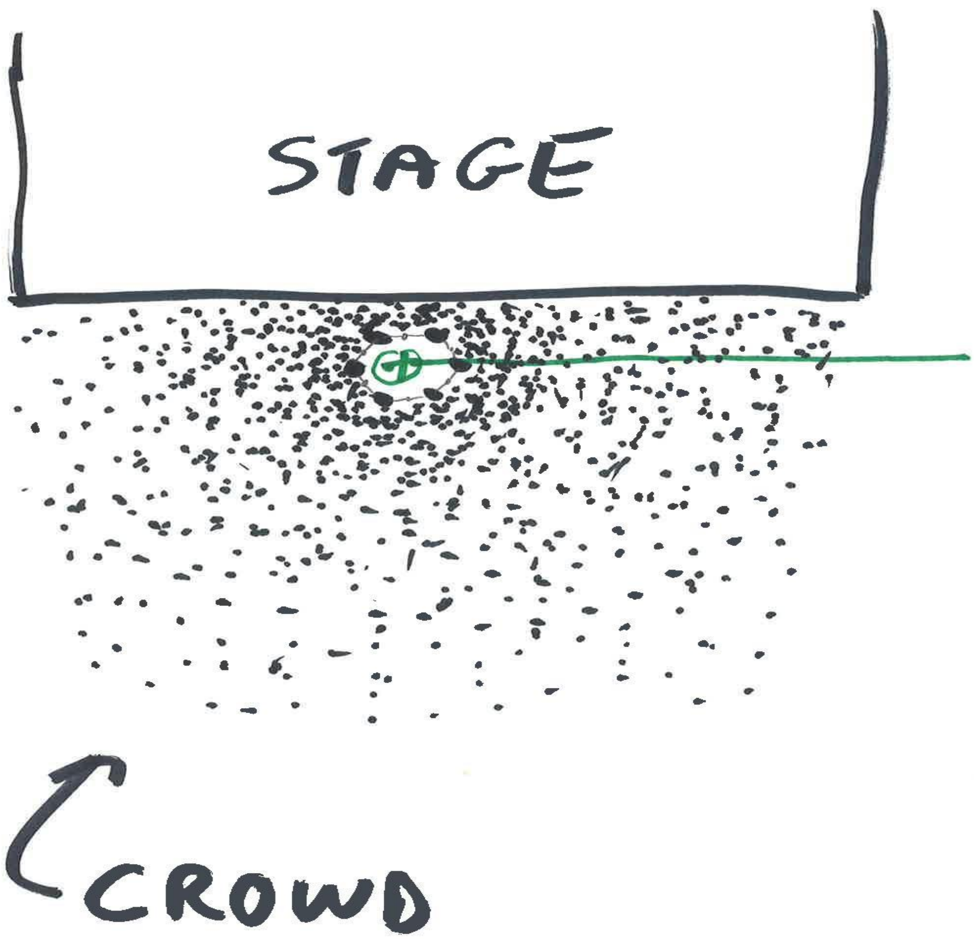


You are stuffed in to this crowd. You and 5 of your friends decide you want a little breathing room so you push against each other to make an opening in this crowd. What happens?

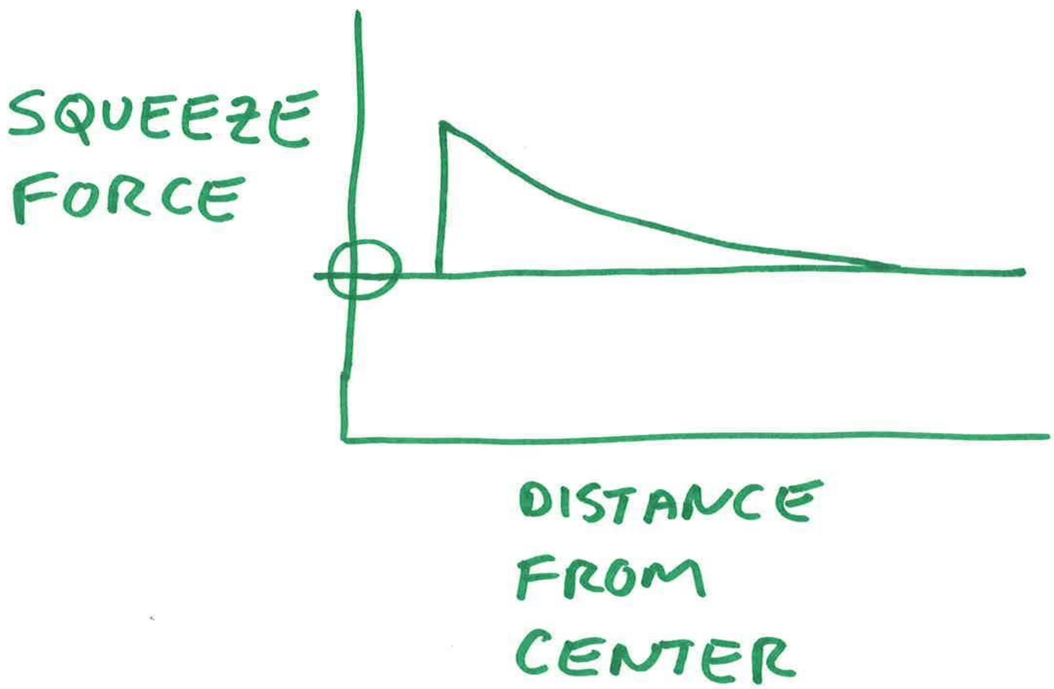


People push back! The closer they are to you, the harder they push because they have other people around them pushing THEM back. The further a person is from your circle, the less they push back. A person at the edge of the crowd really doesn't know that you even made an opening in the crowd.

Being engineers, we need to collect data to analyze the situation. We climb on top of the crowd and take a survey – we ask each person along a line from the middle of the opening how much squeeze force they are feeling.



And, being engineers, we make a graph of our results to make our boss think we're doing something useful, not just climbing on top of people in a crowd.



Survey results show that the closer to the edge of the opening the person is, the more squeezed they feel.

We also discover that we are in a concert in hell – it will never end, and the squeezed people will remain squeezed forever.

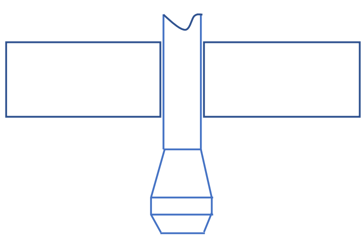
This is very much like what happens in a coldworked hole. The material at the edge of the hole is in a high state of compression, but unlike in a crowd the material distant from the edge of the hole will be in a slight state of tension to balance out the compressive stress at the edge of the hole.

The effect of coldworking is not to work harden the material, it's not magnetic or magic – the result is to lock in a mechanical compressive stress at the edge of the hole, even though there are no external loads on the structure.

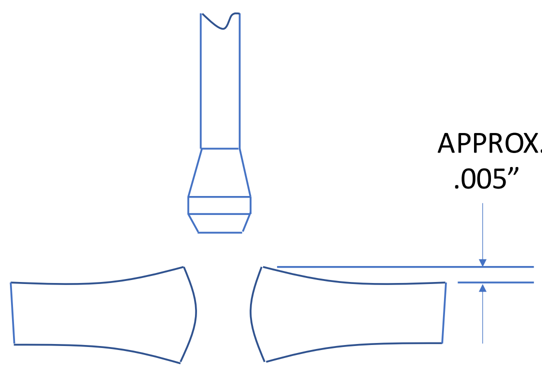
This compressive stress delays crack formation under cyclic loading.

2 steps forward, one step back – there are always side effects from some process change. One of the more significant ones with coldworking is the volcano effect.

With coldworking or metal forming of any sort, the first law is – the material has to go somewhere! Ideally, in hole coldworking it would go sideways into the part being coldworked. Mother Nature being the bitch she is though, the material will take the path of least resistance – at the surface of the part, the top and bottom of the hole, it will squirt out there since nothing is restraining it. This results in a double bellmouthed hole and a "volcano" that is approximately .005" high on both ends of a hole.



BEFORE COLDWORK

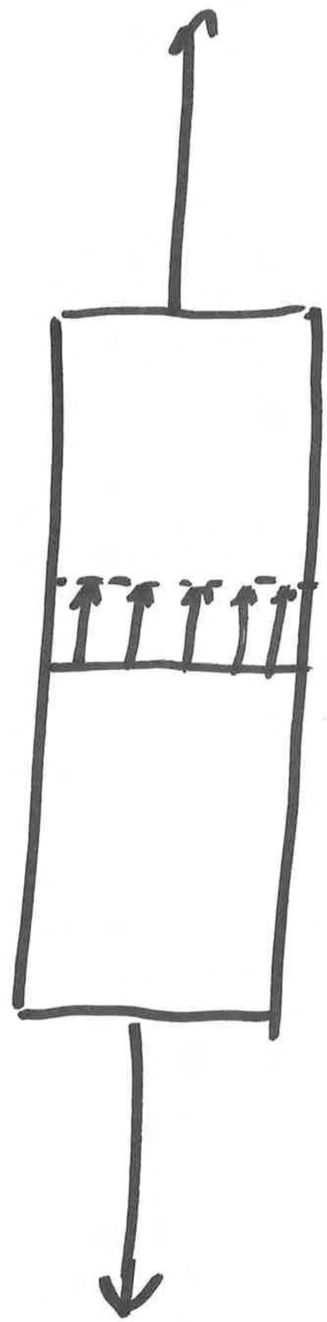


On the one hand, the volcano regains a little bit of cross section of material so there is a slight reduction of stress near the hole. On the other hand, the part is now around .010" thicker than it was near the hole – so for a multi-part stackup, you can gain a fair amount of thickness in the vicinity of a coldworked hole. The volcano can be machined or sanded off with little effect on fatigue life, but then maybe you have also removed the corrosion coatings on the parts as well. Or if the assembly being coldworked requires very precise fits, they won't be so precise any more. After coldworking, the hole is no longer a cylinder, so if a precise bolt fit is needed the hole will need to be reamed after coldworking. It's just something to be aware of on a coldworked hole.

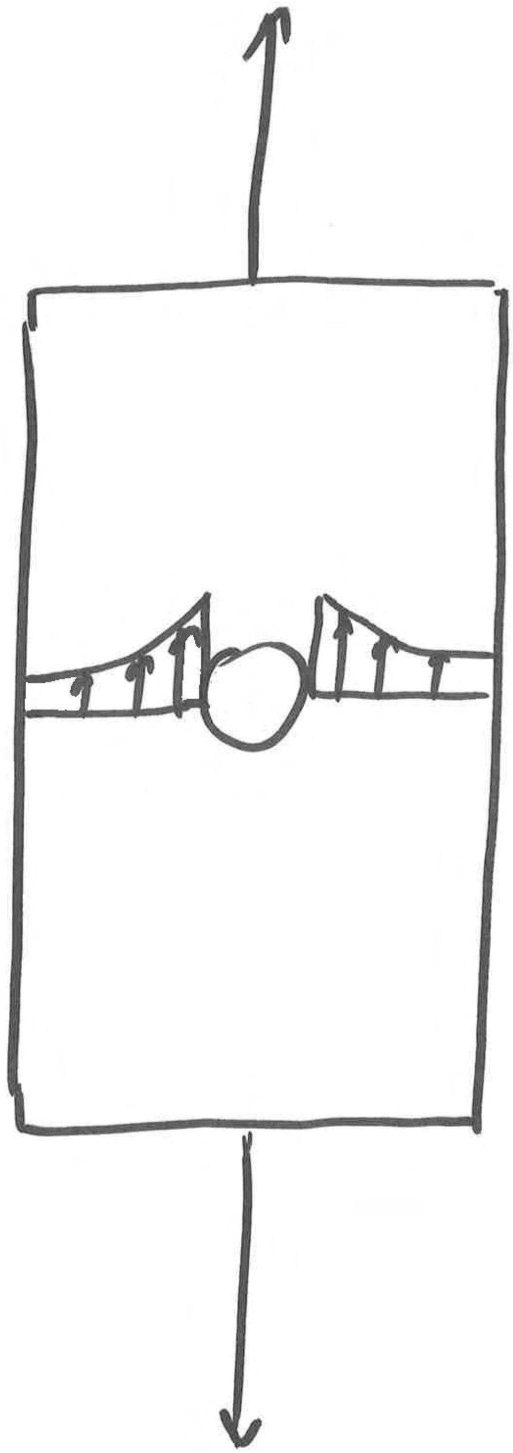
Another important issue with coldworking is – how do you know the hole has been coldworked? Imagine the volcano has been removed and the coldworked hole has been post-reamed. Was it coldworked? Unfortunately there is no simple, shop floor friendly way to know if a piece of metal has residual compressive stress in it. Coldworking is very much a controlled input variable process. If the start hole, mandrel and sleeve thickness are right, you will get the correct expansion and all is well. If these input variables are not controlled, all will not be well.

Coldwork tool manufacturers sell a range of QC tools to check these variables. Fortunately checking diameters of things is a very well established science.

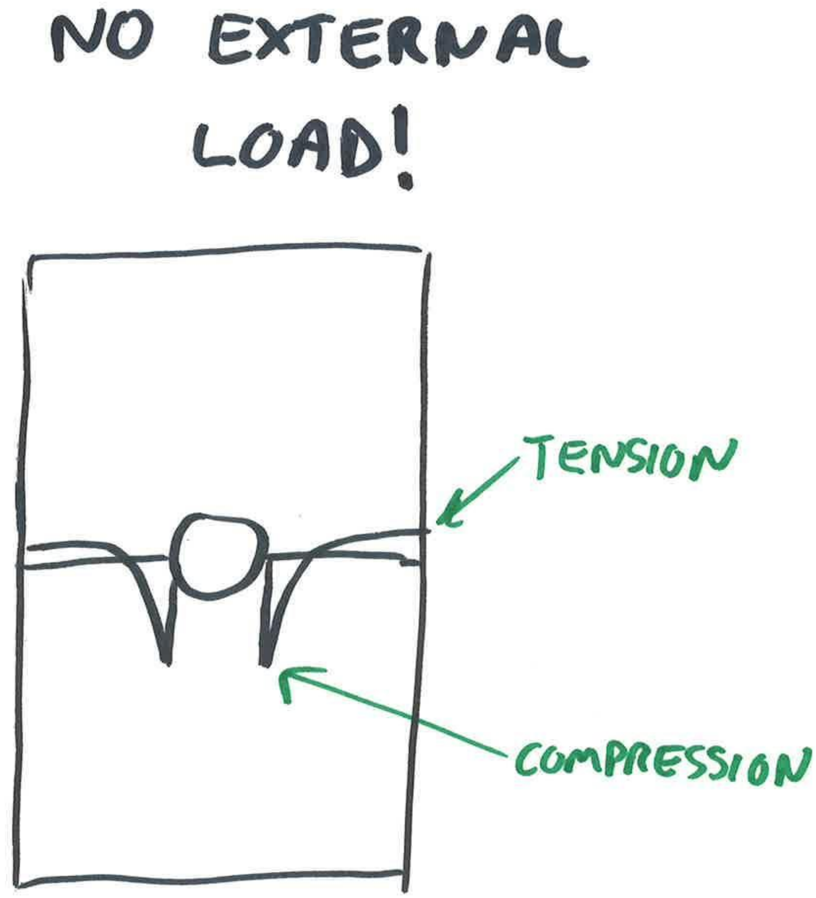
Now consider a piece of structure in tension – a simple strip where we pull on the ends.



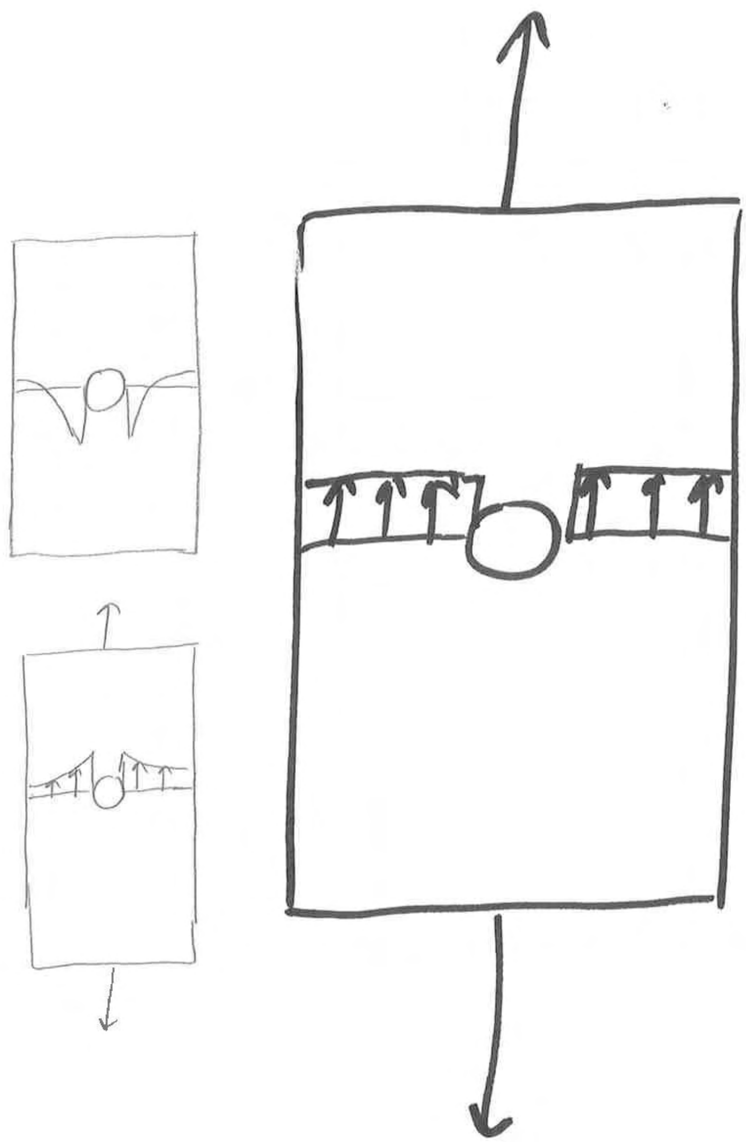
This gives us a nice, even stress distribution – easy to understand and analyze. Unfortunately, a lot of aircraft structures don’t look like this, they are full of holes that tie them to the next part in the load path. Pulling on a piece of metal with a hole in it gives us a stress distribution with more stress at the edge of the hole.



This is bad – a 20% increase in load will cut fatigue life in half. Enter the coldworked hole with this stress distribution -



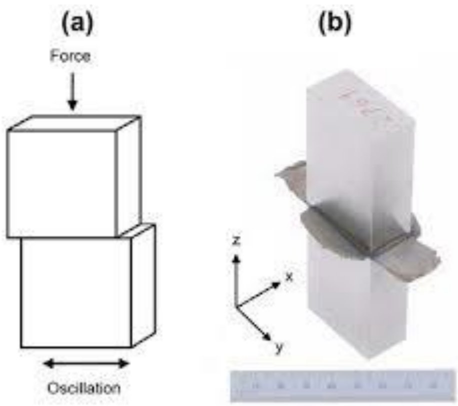
It has a locked in compressive stress at the edge of the hole, perfect for counteracting the higher stress at the edge of the hole from external loading. Combining the 2 states of stress, we get a more even stress distribution across the metal -



Thus reducing the stress riser effect and increasing fatigue life.

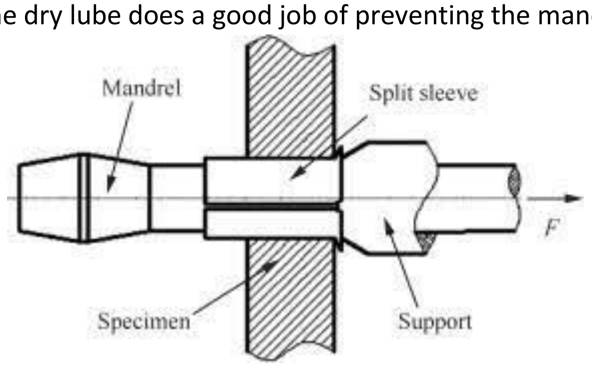
How do we actually accomplish this process? Generally by pulling a tapered mandrel thru the workpiece with a hydraulic puller. Pull forces can range from a few hundred pounds for a very small hole to hundreds of thousands of pounds for a really big hole. Typical pull forces range from 3000 to 30,000 lb. .

Aircraft materials are strong. It takes considerable pressure to make these materials move, the surface pressure on a mandrel expanding a hole is typically 1.5 - 2X the yield strength of the material – so easily in excess of 100,000 PSI for aluminum and twice that for titanium. Combine this with sliding movement as the mandrel is pulled thru the material and you have a recipe for welding a mandrel to the aircraft



structure.

The solution to this problem was to use a liner between the hole and mandrel – this liner also creates the expansion needed to actually expand the hole. The liner is known as a “sleeve” – these are made from high strength stainless steel and have a graphite/moly disulfide dry lube coating on their inside diameter. The dry lube does a good job of preventing the mandrel from welding itself to the sleeve or



the airplane.

As we all know in the engineering world, when you solve one problem you generally get 2 more to solve. This is great for job security. In the case of sleeve cold working, several issues arise:

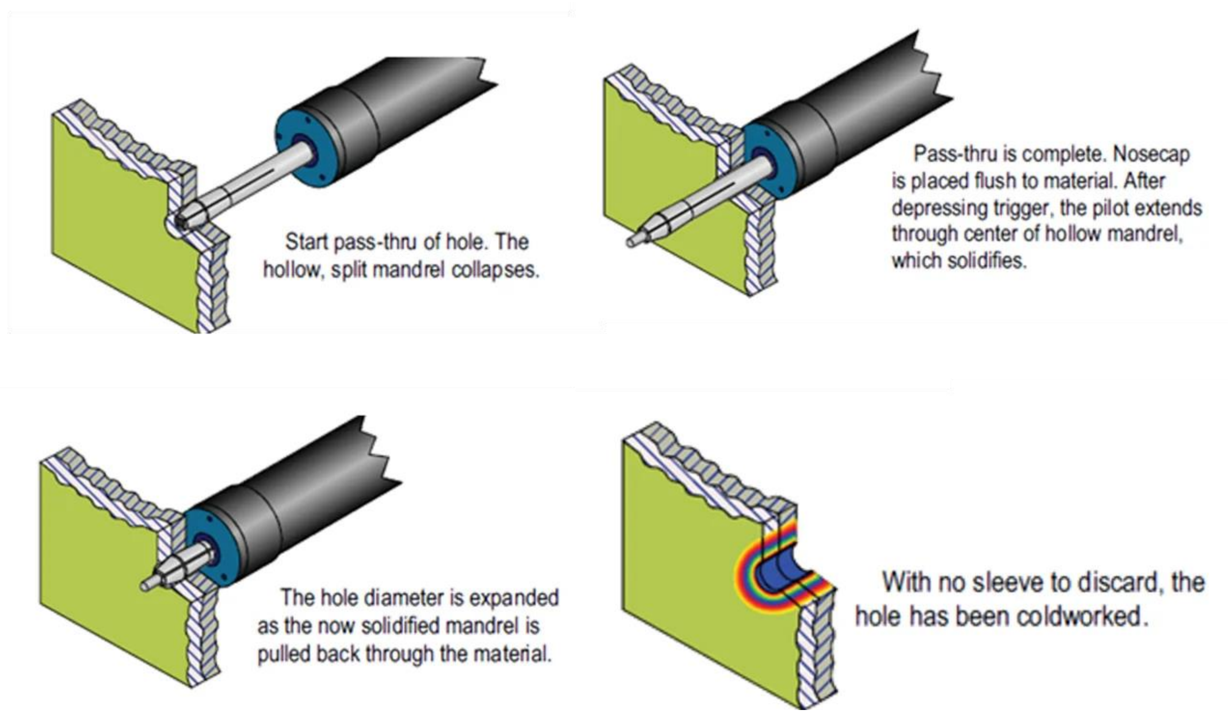
1. You need to buy and inventory sleeves.
2. You need to put them on a mandrel
3. You need to get them out of the hole after coldworking
4. You can only use them once, the used ones get thrown away
5. The sleeve is split so it can be installed on a mandrel, material is over-expanded at the split

6. In many cases, the split in the sleeve must be oriented to a low stress side of a hole – error prone!
7. Any drilling lubricant in the hole can cause the sleeve to fail in buckling in the hole, scrapping it

An engineer at Boeing took a crack at solving these problems. He concluded that most of the problems with coldworking originated with the sleeves. Why not develop a coldwork process that could eliminate the sleeves?

He worked on it and started developing the split mandrel process. He was never able to get the process to work and retired from Boeing. He asked Boeing if he could have the rights to this process when he retired, Boeing said yes and gave it to him. He promptly tried to sell this process to the only 2 companies in the world that made coldwork tools at the time. One said no, the other took it on and got it working fairly well.

The issue of welding workpiece material to the tool was dealt with by using Boelube as a lubricant. This has the major advantage that boelube lubricant left in the hole from drilling operations actually helps the process, as opposed to sleeve coldworking where lubricant in the hole can cause sleeves to fail in buckling.



Boeing became the largest user of split mandrel coldworking, processing millions of holes starting in the 1980's – generally in lower panel wing skin to spar joints or lower wing skin splices.

Split mandrel coldworking solved all of the problems with sleeve coldworking and is probably 5X faster than sleeve coldworking as a bonus. But as we know, solving one problem creates new ones:

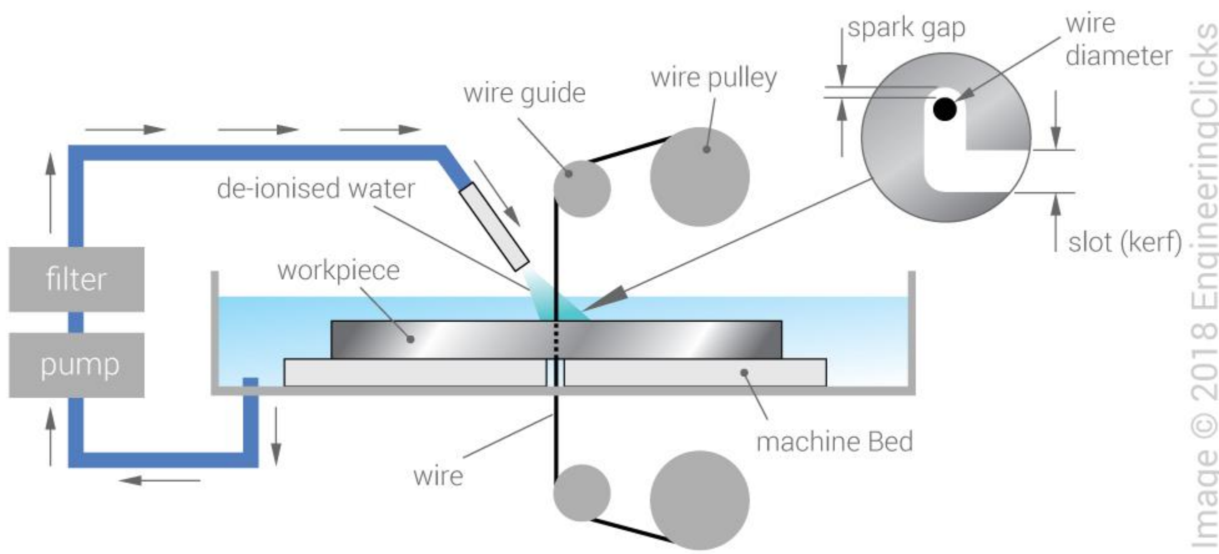
1. The mandrels are prone to breakage. Broken mandrels in airplanes are difficult to remove.

2. Split mandrel coldworking is limited to use in aluminum, mandrels are not strong enough for titanium.

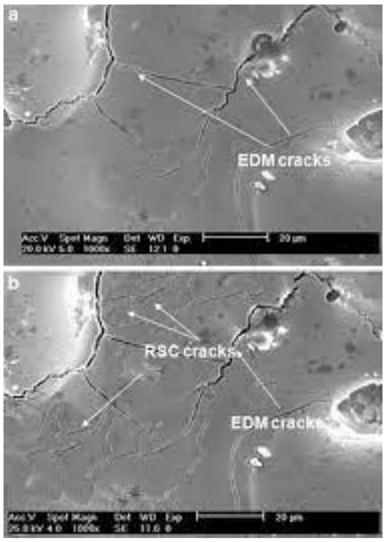
More and more titanium is showing up on airframes, and aluminum/titanium stackups are not unusual. Thus sleeve coldworking is still very widespread.

No work has been done to improve the basic split mandrel process since the 1980's. Electroimpact has undertaken a project to use more modern materials and manufacturing process to improve the strength of the current design of split mandrels.

Current split mandrels have slots made by the wire EDM process. This is an efficient, highly developed way to cut very accurate contours in anything that conducts electricity.



But, it's always two steps forward, one step back. Wire EDM is mainly used for stamping dies – these are mostly compression loaded tools. EDM works by vaporizing tiny bits of material, one after the other, at a very high rate of speed. Some of the vaporized material will re-condense at the surface of the workpiece. This material is a combination of the workpiece material, whatever the EDM wire was made of, and atomic hydrogen and oxygen from the dissociated water that is surrounding the whole process. This condensed layer also cools extremely quickly. As it cools and contracts from its melting point at the surface of the part, it cracks.

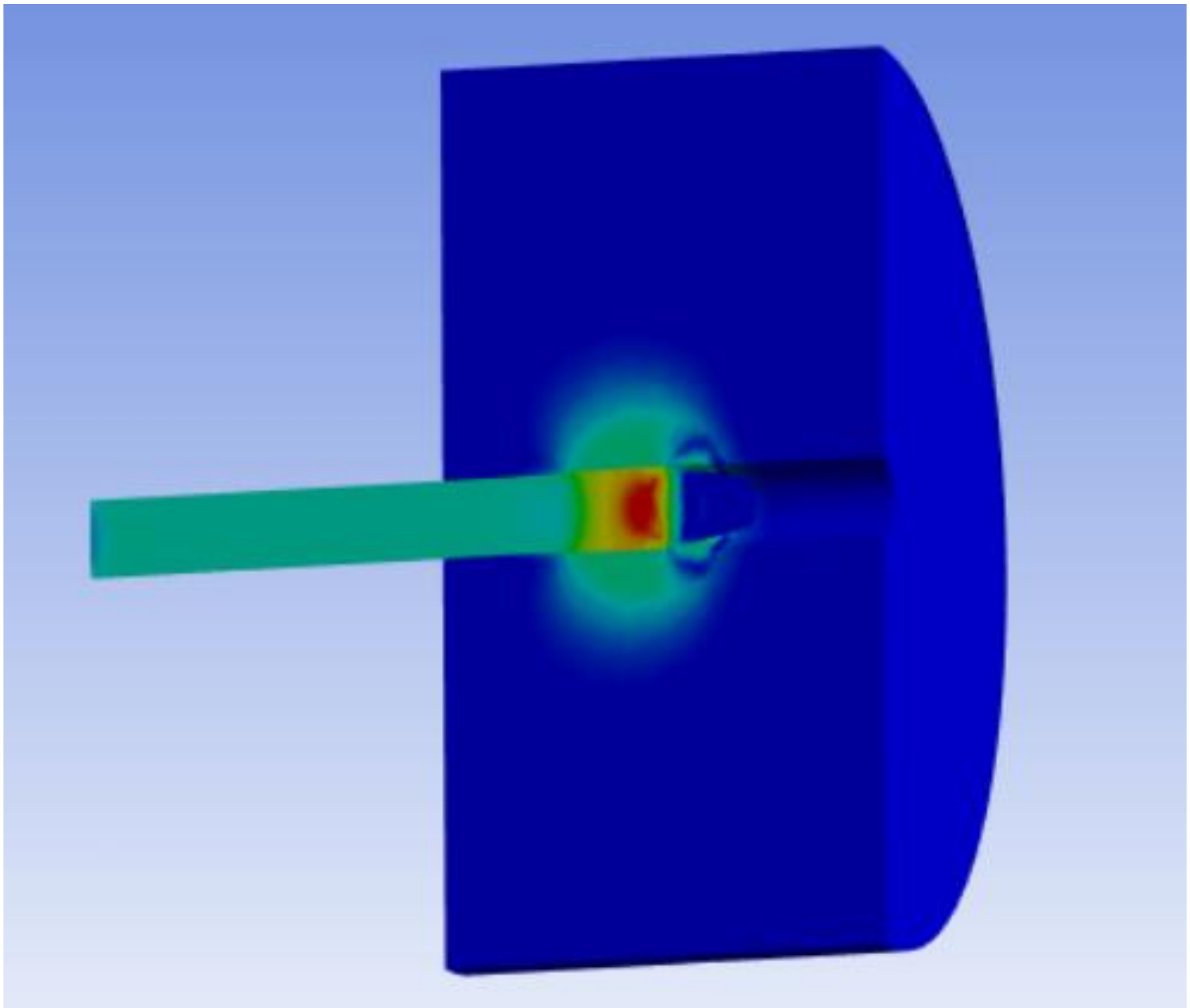


Since a coldwork mandrel is under tension to pull thru the material, the last thing you want is a collection of surface cracks to start a tensile failure! The high strength alloys that mandrels are made of are a very fine-tuned beast, they have very specific grain structure, alloy composition, lack of impurities and careful heat treat. The EDM process pretty much demolishes all of this – but only on a very thin surface layer. Unfortunately this is generally where cracks start in a part, at the surface.

The solution to the slotting problem? Don't EDM the slot! Electrompact will be using an undisclosed process that does not vaporize the surface or heat it to create a smooth, accurate slot.

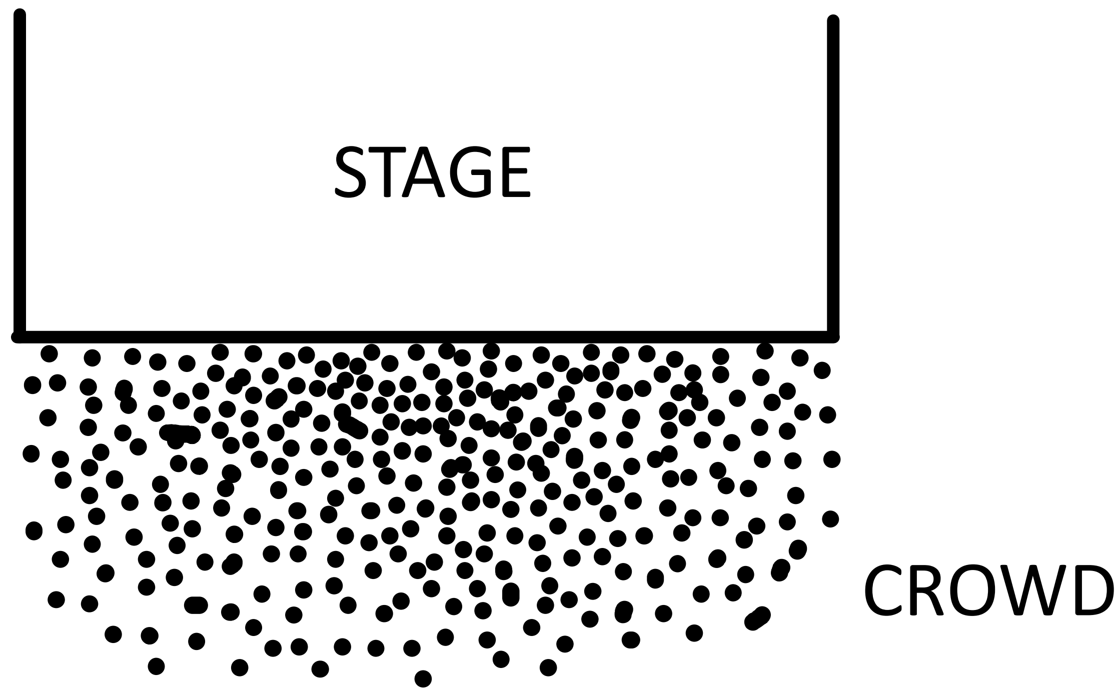
With better materials and manufacturing processes, we feel that we can improve the split mandrel process.

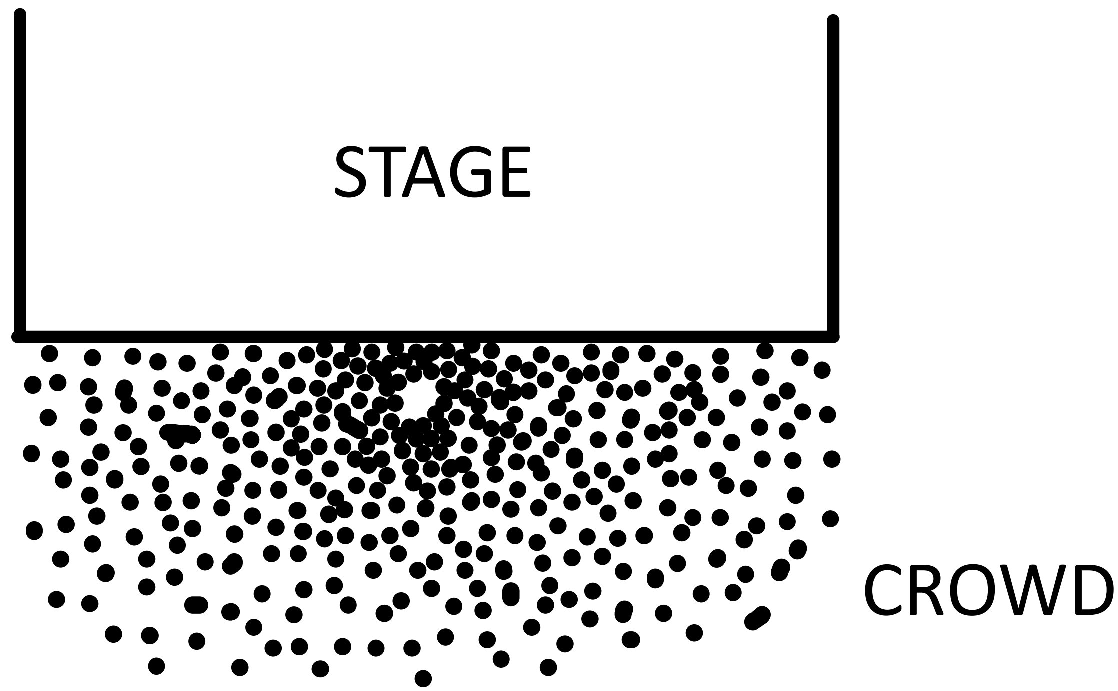
Will coldworking work for you? It depends! Non-linear finite element analysis programs do a good job of simulating the effects of coldworking a hole. You can get very close approximations of post-coldwork hole shape, volcano, residual stress and any distortion of the parts due to the locked in residual stresses in the parts. Fatigue testing will verify the results of the FEA analysis and also prove out the tools and processes needed to accomplish coldworking in your application.

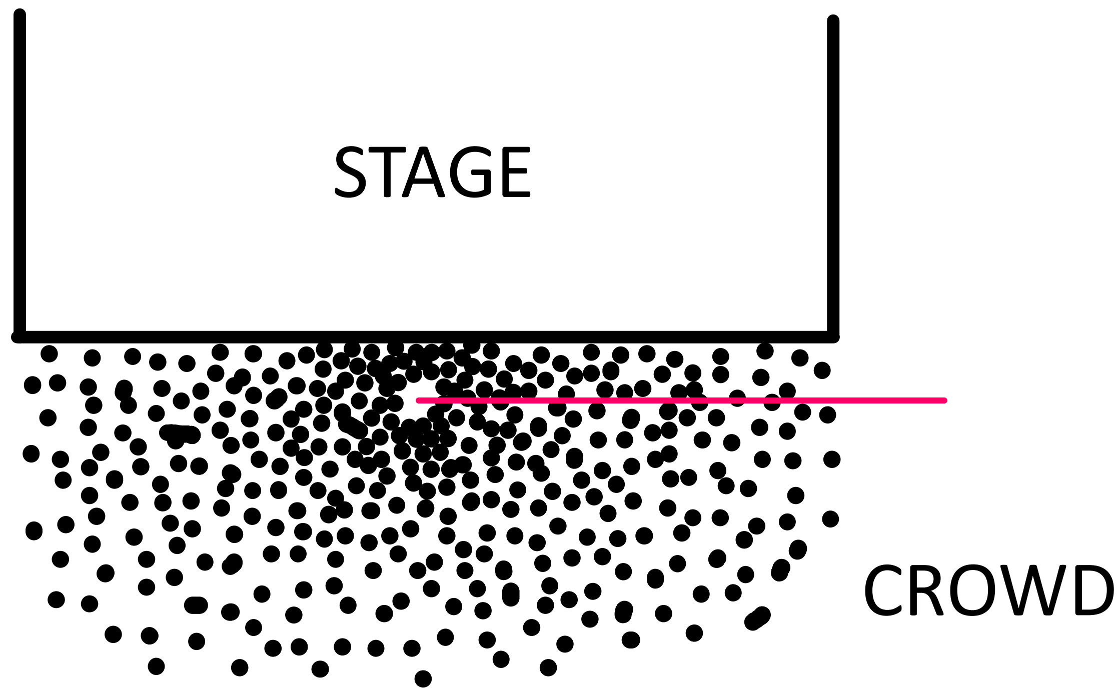


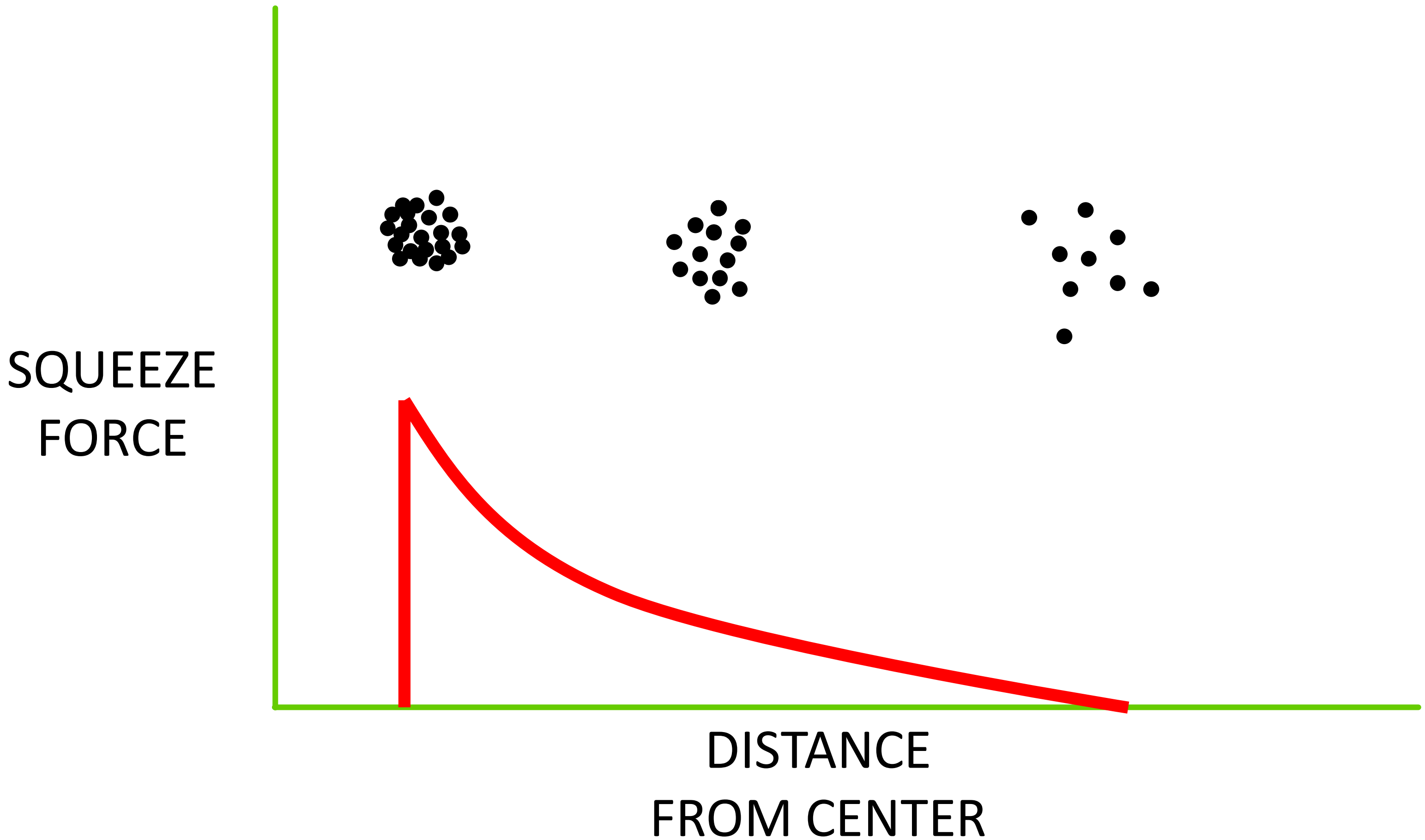
THE END

SPLIT MANDREL COLDWORKING PRESENTATION


STAGE
CROWD

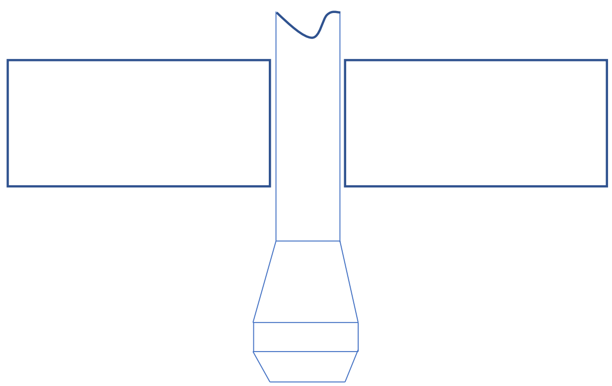

STAGE
CROWD


STAGE
CROWD

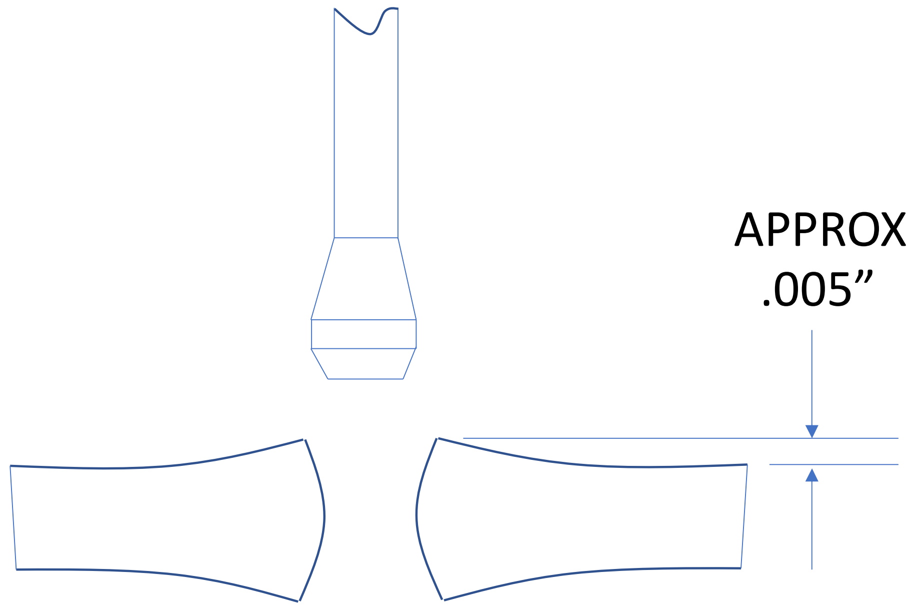


SQUEEZE
FORCE
DISTANCE
FROM CENTER

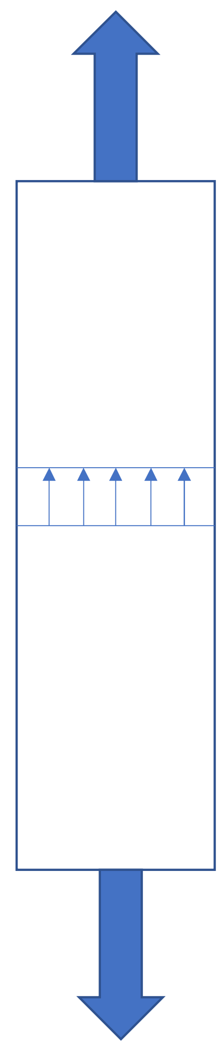
VOLCANO EFFECT



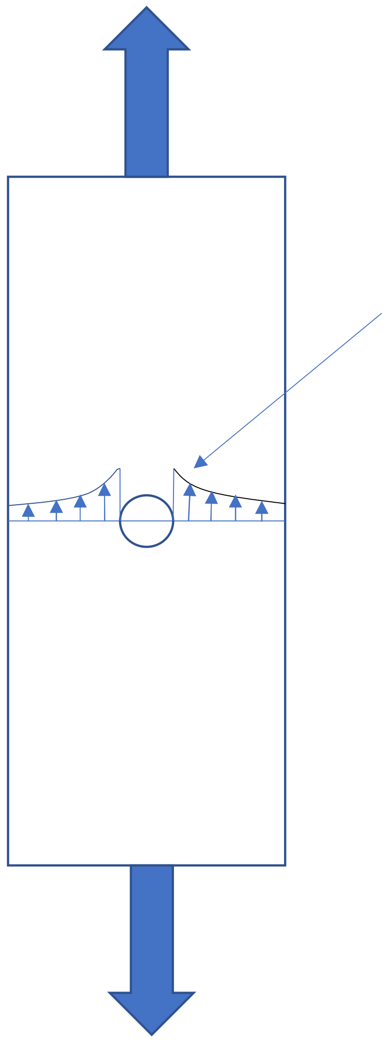
BEFORE COLDWORK



AFTER COLDWORK

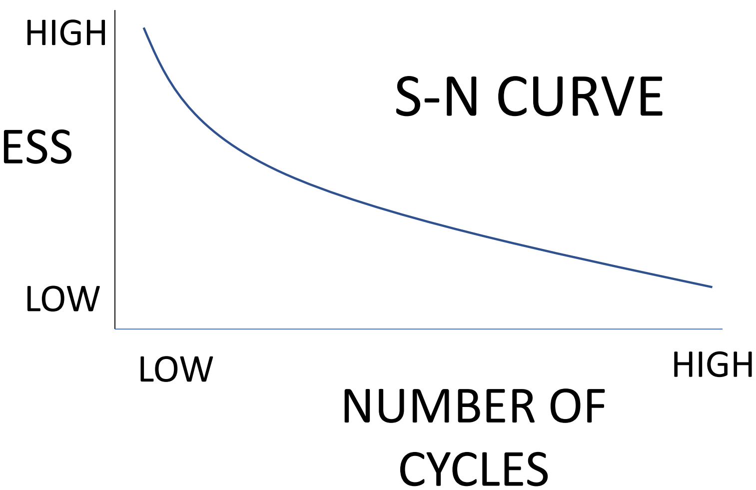


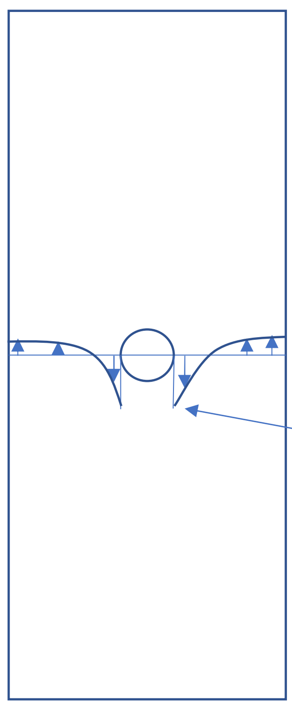
STRUCTURAL PART – NO HOLES –
NICE EVEN STRESS DISTRIBUTION



STRUCTURAL PART WITH ANNOYING FASTENER HOLE.

HIGH STRESS AT EDGE OF HOLE.

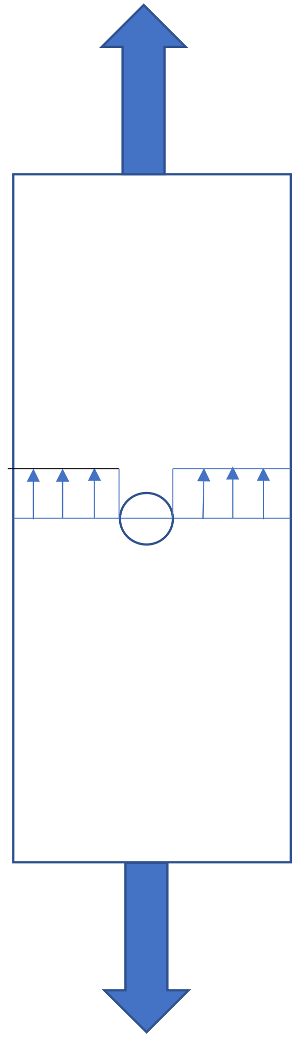




COLDWORKED HOLE –

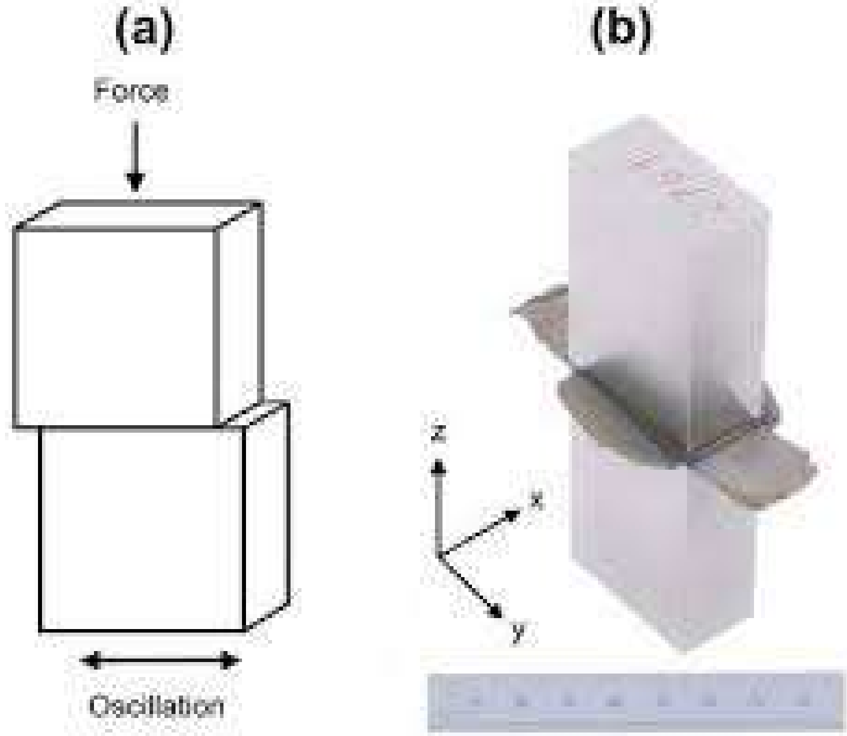
NO EXTERNAL LOAD ON STRUCTURE.

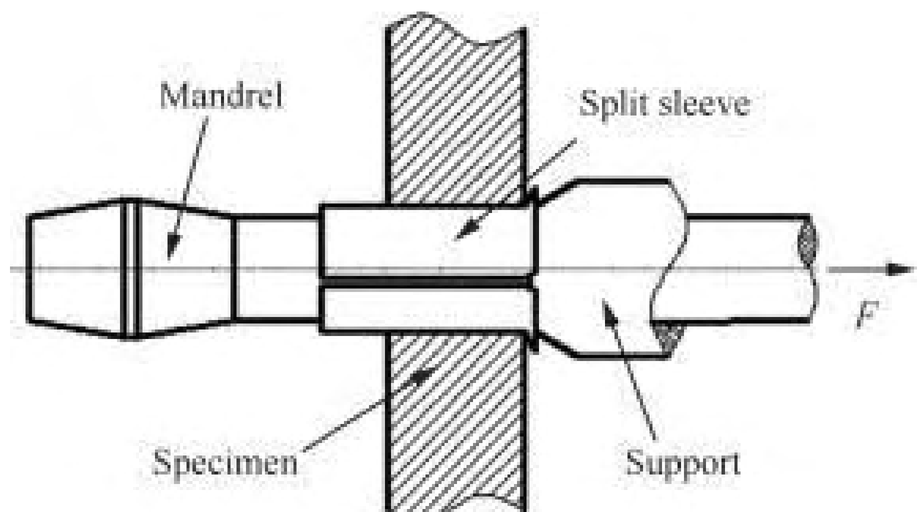
HAS LOCKED IN COMPRESSIVE STRESS AT HOLE EDGE!

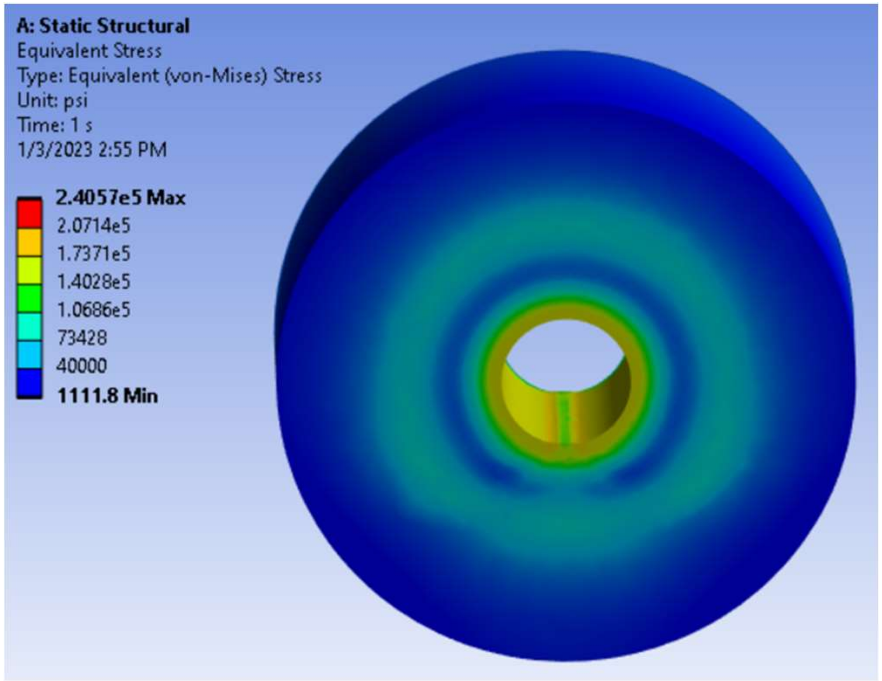


COLDWORKED HOLE –

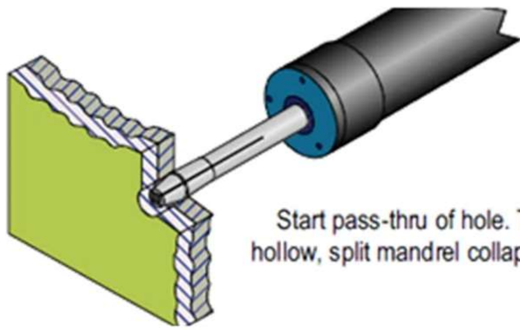
REDUCED STRESS AT EDGE OF HOLE IN LOADED STRUCTURE.


(a)
Force
Oscillation
(b)
z
x
y

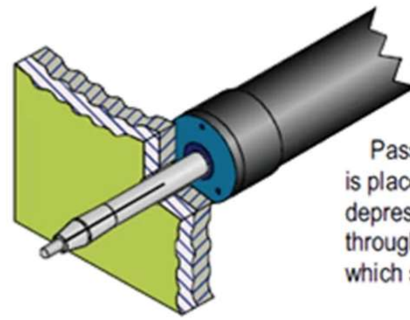

Mandrel
Split sleeve
Specimen
Support
F



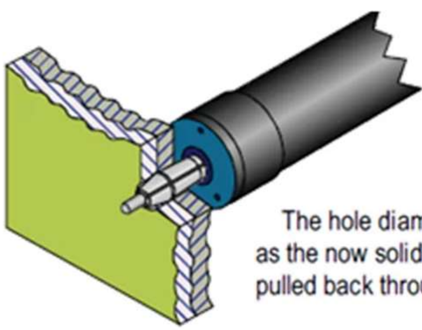
NON – SYMMETRICAL RESIDUAL STRESS DUE TO SPLIT IN SLEEVE



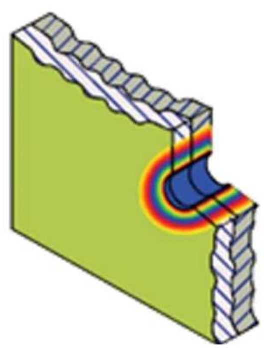
Start pass-thru of hole. The hollow, split mandrel collapses.



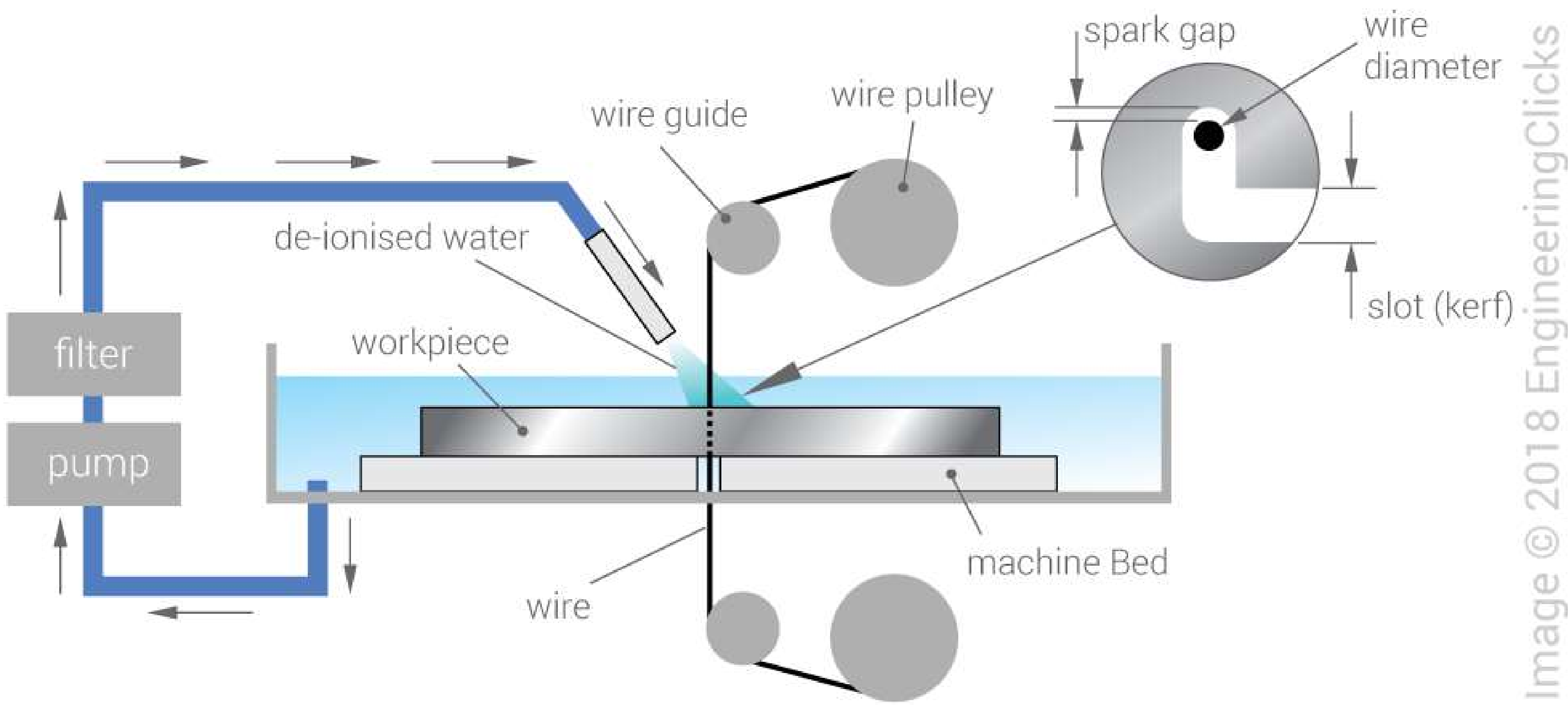
Pass-thru is complete. Nosecap is placed flush to material. After depressing trigger, the pilot extends through center of hollow mandrel, which solidifies.

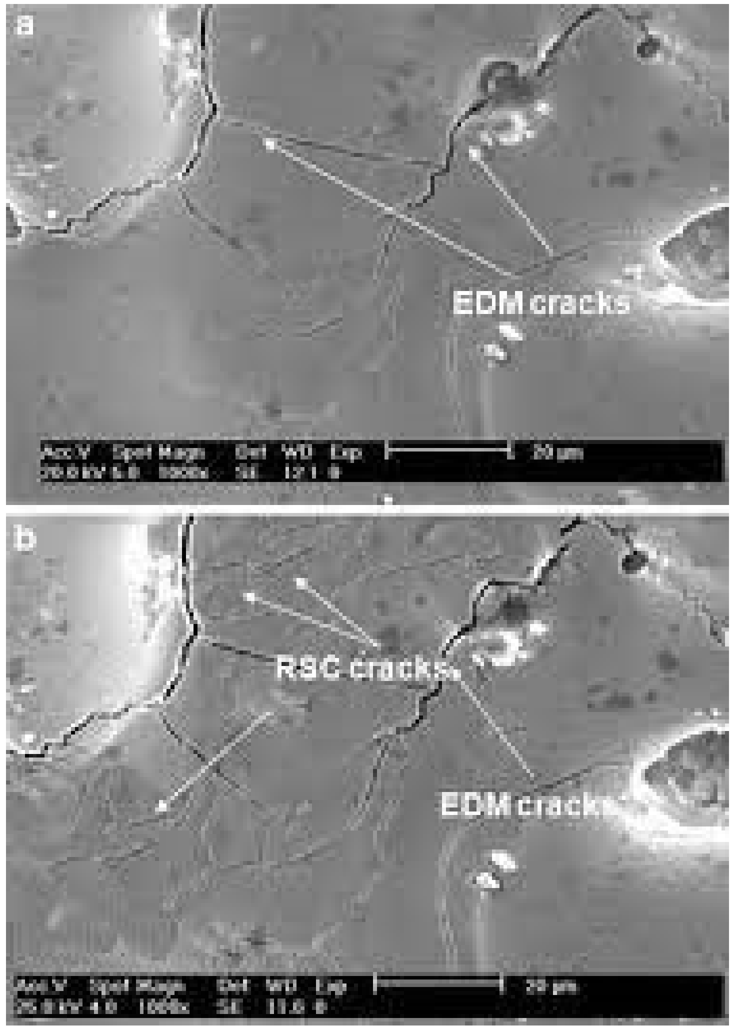


The hole diameter is expanded as the now solidified mandrel is pulled back through the material.

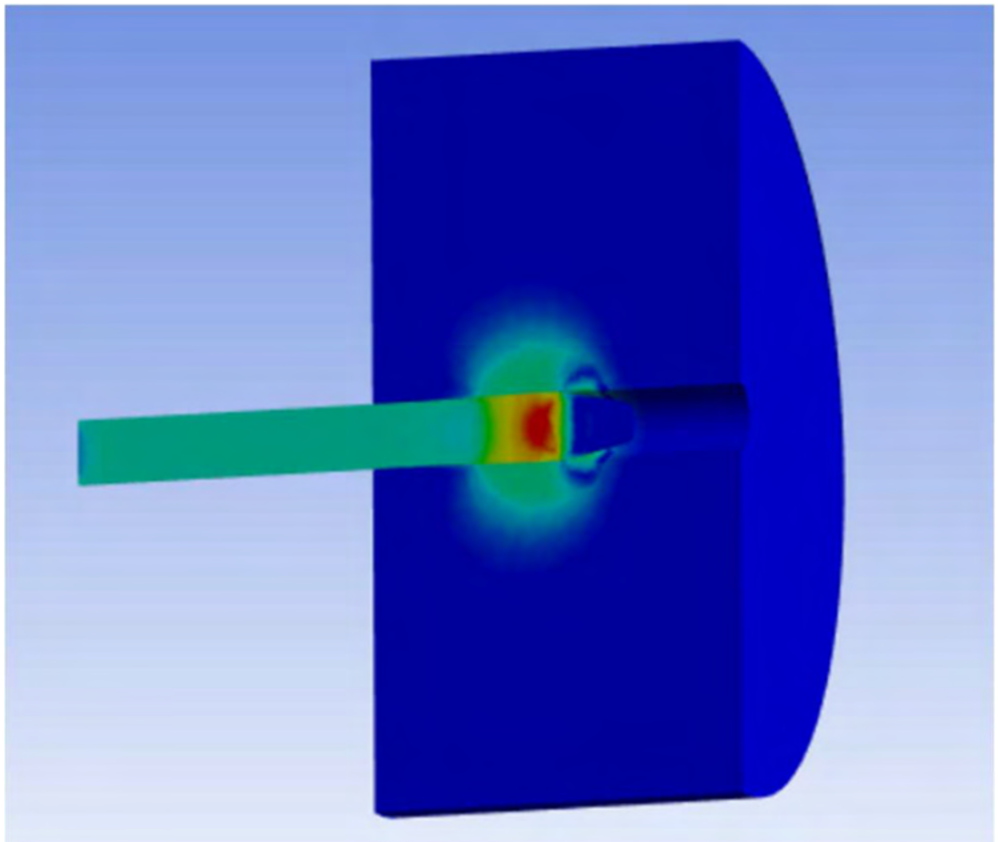


With no sleeve to discard, the hole has been coldworked.


spark gap
wire diameter
wire pulley
wire guide
de-ionised water
filter
pump
workpiece
slot (kerf)
wire
machine Bed
Image © 2018 EngineeringClicks



a
EDM cracks
20 µm
b
RSC cracks
EDM cracks
20 µm



Thanks for watching!

Paul Shemeta 425-609-4591
paulsh@electroimpact.com

Electroimpact
4413 Chennault Beach Road
Mukilteo, WA 98275
USA