White paper
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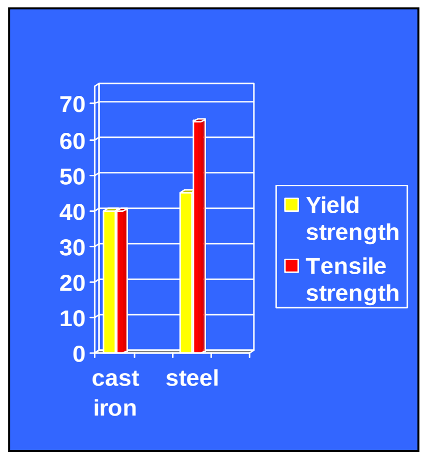
Understanding cast iron and repairing damaged castings permanently

Why has cast iron continued for over a hundred years to confound, confuse, scare and frustrate, while succeeding as one of the most important metals ever developed? The money in wasted labor, downtime and scrapped parts runs into the millions of dollars annually because of experimental welding and fear of failure.

This paper will cover these issues in step by step format that will explain cast iron in simple terms and break down the myths that have given way to serious misperceptions about cast iron.

My objective is to share valuable information I have assembled over the past 40 years of successfully repairing castings on a daily basis with many different methods and to help maintenance and repair personnel in the gas compression industry understand damaged cast iron repair solutions well enough to make informed decisions for the repair of compressor castings.

1. Why cast iron cannot be welded the way other metals can



Cast iron differs from other ferrous metals mostly by the extra carbon that is found in flake or spherical form. The presence of the extra carbon interrupts the continuously linked structure of iron molecules. This in essence prevents gray cast iron from having a differential between yield point and tensile point. It is easier to envision cast iron as having no yield point and only a tensile point. Many other metals display a yield point where the metal can stretch before reaching the tensile point where it will break to relieve the strain. A soft steel bar can easily be welded because the area adjacent to the weld can stretch as the weld cools and contracts.

Cast iron cannot bend or stretch and without a yield point differential it will simply crack to relieve the stresses of a weld if there is no high temperature preheat. Most welders have heard that preheating helps prevent cast iron from cracking and they are right as long as the temperature is high enough. This is where most of the problems occur. Because most welders don't have access to an oven where the casting can be heated to the right temperature and the welding rod manufacturers publish preheat temperatures of 600˚F and lower, serious mistakes are made and additional damage occurs within the HAZ. This is the single biggest reason cast iron has such a bad reputation.

2. How cast iron responds to heat

Cast iron can absorb and transfer heat fairly quickly and evenly while staying very straight. This is why it is the perfect metal for engine blocks and cylinder heads. The forces that cause cast iron to crack are always mechanical and not mysterious or the result of a mythical transformation.

Again I want to clarify that cracks are caused by mechanical forces which are obvious in freeze damage and impact. However, so are heat cracks. Heat cracks are a direct result of expansion and contraction in a confined area.

Another challenge is that cast iron is easily hardened by heating to a high temperature followed by rapid cooling. Hardening occurs when cast iron is heated above 1500˚ F. and subsequently cooled to 1100˚F quickly.

Hardening is exactly what happens when any type of electric welding is used with a preheat temperature below 1500˚F. And, of course, few people have the equipment and training to preheat properly. So not only does welding usually cause more cracks, it also causes hardening, which makes it very difficult, if not impossible, to machine or drill and tap afterwards.

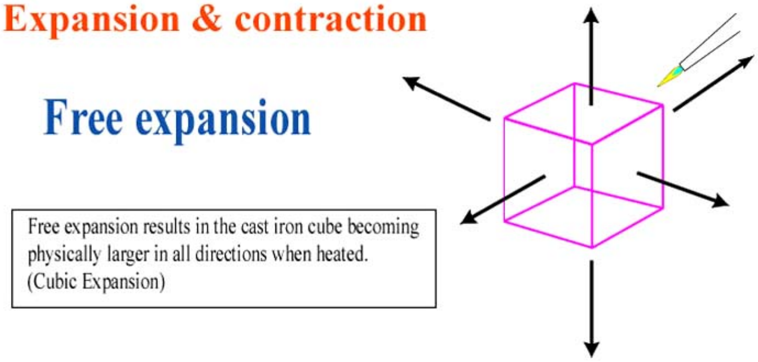
Hardening does make cast iron brittle because all of the good ductility and vibration dampening qualities are destroyed when it becomes hard. Cast iron can reach 60 Rc when not preheated hot enough.

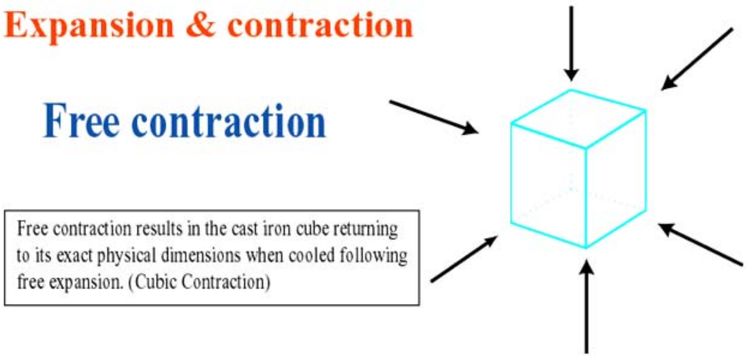
An additional issue is welding causes distortion. Even under the best oven welding situations there is still distortion caused by the contraction of the weld deposit near the weld. This is always apparent when machining any welded part. If the welding is done properly there will always be a shrink or low spot next to the weld or brazing. The high temp preheat allows the iron next to the weld or brazing deposit to develop an artificial yield point and stretch the way steel does to relieve the strain that occurs when the weld solidifies and contracts as it cools. Stress relieving of a proper cast iron weld or braze occurs as it cools from 1800° to 1200º F.

The bottom line is, the weld contraction causes a pulling force in all situations. It is how the distortion is dealt with that determines whether there will be stretching or cracking.

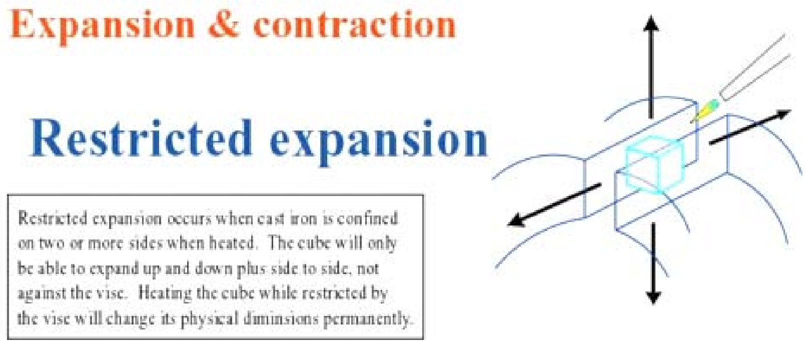
3. Heat cracks and expansion / contraction

Heat cracks are caused when confined expansion is combined with confined contraction. The following example will help illustrate this concept. When metal is heated it must expand. When it is free to expand equally in all directions there is no change or pressure created. When it cools and contracts the heated area is free to contract uniformly in all directions so no change to the metal occurs.

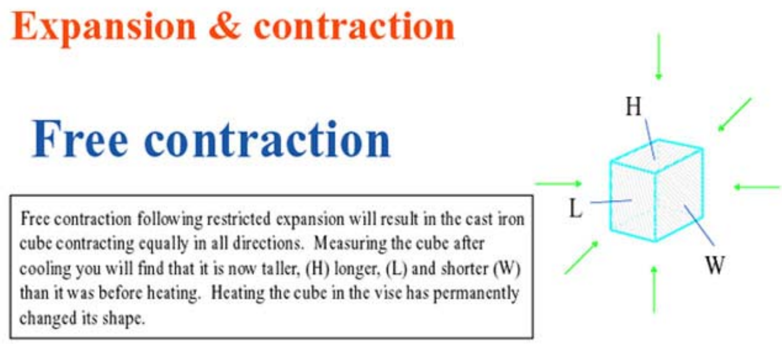




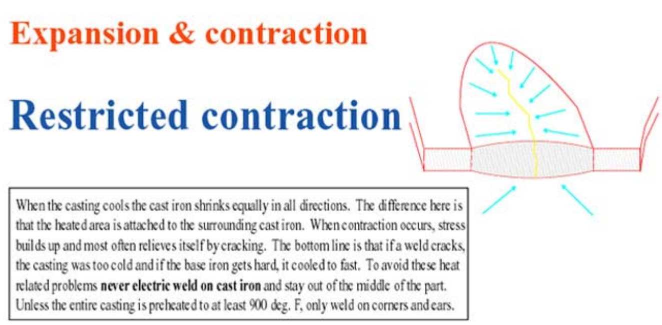
This is the case when heat is applied to an entire part or an ear or a corner of a part. This is why oven heating works. However, when only a portion is heated near the center of a part the area is not free to expand equally because it is contained by colder metal surrounding the heated area. Specifically in this case the heated area does expand equally but in a non-uniform way so that it only expands in one direction.



When this occurs the metal usually gets thicker during the heat up phase.
The damage is done at this point because the physical dimensions of the heated area are permanently changed.



When it starts to cool it's starting from a different shape so as it contracts uniformly there is a significant strain placed on the cast iron. This most often results in a new crack forming near the original one. People fail to understand that it is the heat that causes the cracking and not the welding rod or method.



Bottom line is, it's the heat that creates the mechanical forces and hardening that result in disaster and not the welding rod.

After welding "If it cracked it was not hot enough, if it got hard, it cooled too fast"

4. Cast iron can be welded and brazed successfully

High temperature pre-heat welding and brazing can be performed with 100% predictability just like other metals. If the casting is properly preheated to a high enough temperature the weld will always become completely stress free and annealed to be free from the effects of hardening.

In most cases structural repairs can be successfully accomplished by brazing with bare bronze rod, acetylene torch, and flux.

Compressor cylinder damaged trying to remove the liner with an air arc

A 36 inch long, ¾ inch groove was cut into the liner bore

In this repair the groove had to be filled in so the bore could be machined to receive a new liner.

Bronze was chosen to limit distortion and to make it possible for the welder to reach inside to do the brazing. Fusion welding would have been too hot for the welder working inside.

Building the oven with fire brick and ceramic blankets

Pre-warming by hand

Brazing the upper half of the groove

Brazing to fill the groove

The bronze is 70,000 psi tensile strength whereas gray iron at best is 40,000 psi. Ductile iron is commonly 65.000 psi, the same as mild steel. Bronze can provide a bond that has a maximum strength of 40,000 psi.

The brazing was completed and the bore machined to a slightly larger diameter.

After machining and before the liner was installed, the cylinder was hydro-tested to assure there were no leaks.

5. Fusion welding for high temperature applications

Damaged cylinder head can be repaired by cast iron fusion welding

Another acceptable process is called fusion welding which is performed by first preheating the casting to 1500 deg. F.

The casting will be bright red in color. Cast iron melts at approximately 2400˚ F so there is 900˚ between the preheat and melting point of the cast iron. The welding is done with an acetylene torch and bare cast iron rod which is just a stick of clean cast iron as the filler metal.

The welding process is done by melting the cast iron, puddling the base cast iron and adding filler iron into the puddle. This process is used mostly for buildup and cylinder head remanufacturing. There is more distortion with this process than any other.

Fusion welding involves re-casting areas of the part by melting a deep puddle and adding molten filler iron.

When finished it is basically invisible and has the same characteristics as the original casting.

6. Metal arc and powder spraying for buildup only

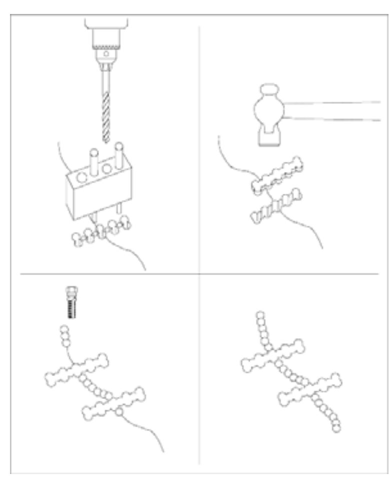
These methods require little or no preheating and are recommended to not exceed 300º F. during the process. The surface is machined a little undersized leaving a rough surface or grit blasted finish to provide a mechanical bonding surface for the spray. These methods are not for strength or to seal a leak.

Mechanical repairs are used to avoid the difficulties associated with welding

7. Mechanical solutions that are commonly used

Sleeving a worn out bore is a mechanical repair that is time tested and proven to be a great solution. Repairing a damaged bolt hole with a thread repair insert is a very well known and successful method for stripped threads. Removing a damaged section and fabricating a new section made of steel to be bolted in can be a very useful way to solve a bad problem.

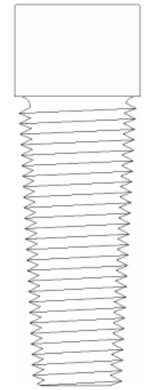
8. Metal Stitching



Metal stitching is the most widely used, accepted and successful method for repairing cracks and attaching new pieces to repair cast iron parts. The concept is nearly as old as cast iron is.

The basic parts include locks that span the crack with lobes that provide grip to hold the crack together and some type of threaded screws, rods, bolts or special pins designed specifically for the purpose. The screws are installed by drilling and tapping threads directly into the crack in a continuous overlapping way that removes the crack completely and creates a pressure tight seal.

Over the years many things have been tried that fall into the category of metal stitching or metal locking. It started with wooden dowels, brass plugs and non-threaded tapered cast iron plugs driven into drilled holes.



One of the simplest methods uses tapered threaded cast iron plugs installed in an overlapping fashion along the crack. This is how I started repairing cracks without welding. It does work in some situations but relies on there being enough strength surrounding the repair to contain the spreading force of the tapered screws. This eliminates all structural repairs.

The first patented method was the Harmon process in 1940 that utilized a lock that was installed into a drilled hole pattern and used bolts as stitching pins along the crack.

The next method was the Metalock process patented in 1953 which is still in use. It is available only as a repair service and not as a product. For 35 years it was the only process available for industrial repairs, pretty much had the market to itself, and has survived unchanged and unimproved.

I patented the Ironstitch process in 1987 and later patented and replaced it with the improved *LOCK-N-STITCH* technology in the early 90's. The *LNS* technology has seen many additions and improvements since then.

9. When to choose welding and when to choose metal stitching

Oven welding and brazing requires complete disassembly and moving the part to a reputable casting repair shop. The casting will require re-machining as well. The disassembly, transportation, and machining increases the cost and downtime significantly. However, there are many cases where this is the best or only way the part can be saved.

Welding may often be the only solution when small sections are missing or buildup is required and sleeving is not an option. In many cases where welding has been attempted, welding or brazing will be the best option because of the hardening and stress created by the first welding. Cold welding will harden the cast iron to the point it cannot be stitched. In these instances, the entire weld and at least ¼" of cast iron around the perimeter of the weld must be cut out and replaced by a patch or oven welded or brazed.

When possible, metal stitching is usually the preferred method because it does not require disassembly and transportation to a competent casting repair shop. Frequently the repairman can take all the tools required on a commercial airline as checked baggage and fly to the jobsite. Stitching does not cause distortion so most often re-machining is not required. Reducing downtime is normally a very big savings for the customer.

10. Understanding and solving the cause of the damage to prevent future failures is paramount

Failure analysis is always the first step in evaluating the damage and repair method alternatives. Just like all other mechanical repairs, if you don't fix the problem that caused the failure it will happen again. Failures that occur because of an accident or incident are usually the easiest to evaluate.

If there is no apparent reason and the failure occurred during normal operation the cause may be difficult to determine. Cast iron is not subject to fatigue like steel because it doesn't stretch or bend so there is always a direct cause for the crack. Whether or not you can figure it out is another story. The best place to start is to research the history of the part with the manufacturer to see if they will tell you if they have seen this before. If they won't tell you, try asking other people in the industry.

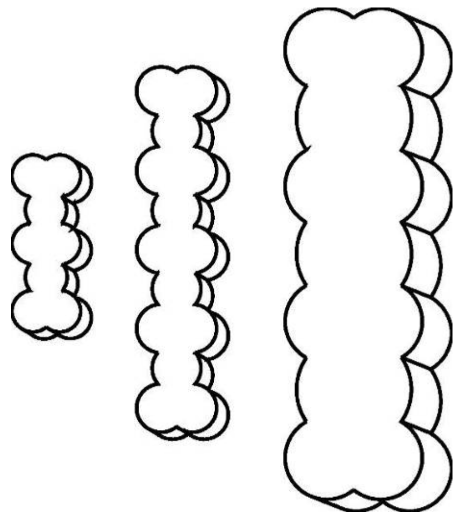
Many castings are under designed, suffer from core shift, are used beyond their design capability or may simply be too weak. The age of the casting can be a clue also. Look at the mating parts and mating surfaces. Look for signs of misalignment or of being placed in a bind under extreme loads. In most cases, some type of reinforcement will be required to add enough strength to prevent it from cracking again. In situations like this restoring 100% of the strength may *not* be enough.

11. Defining the process for engineering a successful repair

The success of a repair depends on how well the repair was engineered to take into consideration all of the operational requirements of the part. Issues like what direction does the load come from? Will the repair be placed in tensile or in shear? Is there a bending moment at play? Is the casting wall thick enough to provide iron to work with? What is the operating temperature? What is the maximum operating pressure? And, of course, what are the safety concerns?

12. Latest technologies provide better solutions than ever before

The repair technologies that are now in use involve all three parts of the basic metal stitching triad.

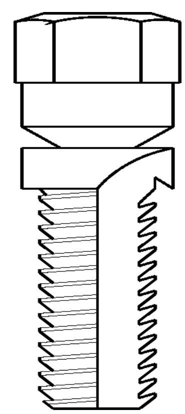


1. *LNS* Locks are by far the strongest and most precise ever produced. The two factors that control the precision fit are the way the receiving hole pattern is created in the casting and the manufacturing process of the Locks themselves.

   The *LNS* Lock hole pattern is created entirely by drilling using CNC precision manufactured drill fixtures, unlike the Metalock process that uses a partially drilled hole pattern with the holes being connected by using a hand held air hammer and a chisel to break the cast iron away between the holes.

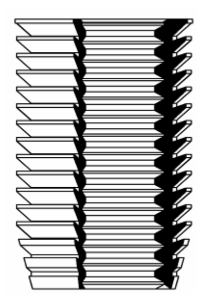
   The *LNS* Locks are cut from 4130 Chromalloy steel plate using a state of the art wire EDM that holds .0005” tolerance. The 4130 is heat treated to 175,000 psi tensile and come in 8 sizes from 1/8” to 1-¼” drill size.

   The Metalock Locks are produced by roll forming with a much higher tolerance out of Invar 36 a Carpenter Metal steel alloy that has a maximum strength of 120,000 psi.and come in 4 sizes. 3/16” to 3/8” drill size. This metal does not expand and contract with the cast iron.



2. *LNS* stitching pins have special patented threads called Spiralhook threads that have a unique ability to pull both sides of the crack together when installed making it possible to restore strength over every linear inch of the crack. They come in sizes from 3/16” to 2-½” in diameter and can be installed up to 8” deep.

   Metalock uses common bolts with standard V threads with standard bolt thread clearances for stitching pins. All V type threads on all standard fasteners produce radial outward forces when tightened that apply a spreading force against both sides of the crack. This reduces the strength of the locks and has little ability to seal.



3. The third member of the triad are devices for repairing damaged and/or cracked threaded bolt and stud holes called Full-Torque thread repair inserts. This is a totally new technology that offers significant improvements to damaged bolt holes especially in the gas compression industry. Thousands of cracked or pulled out and badly damaged bolt and stud holes in compressor frames, cylinders, distance pieces and heads have been repaired and are now stronger than ever and, in most cases, even stronger than the bolts or studs.

Metal stitching to replace a blown out section in an IR compressor cylinder

Large section blown out

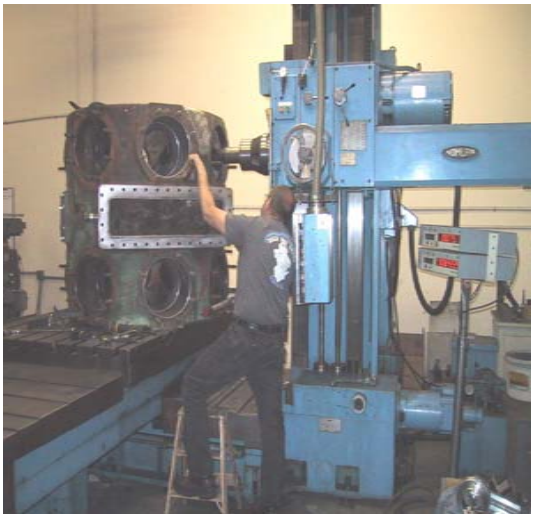
The piece is fit back into the hole

Stitching begins with C3 pins

The CASTMASTER pins are installed overlapping each other along the joint

Lock hole patterns are drilled across the joint to accept L20 Locks for added strength

Blind Full-Torque thread inserts were installed in these bolt holes to add more strength and to seal the bolt holes



All valve port gasket surfaces were remachined.

The cylinder was hydro-tested to 420 PSI to validate the integrity of the repair

This crosshead guide repaired with a combination of metal stitching and Full-Torque thread repair inserts. The broken-out sections are filled in with pieces of steel plate, stitching pins and inserts. This kind of failure is common in gas compressors and can be repaired without removing the casting from the job site.

Several stud holes were pulled out when the studs broke about 1 inch below the surface

A previous Metalock repair attempt failed and allowed the sections to pull completely out

The area outlined by the cracks had to be milled out to receive a steel patch

The pulled areas were milled out to receive the patches

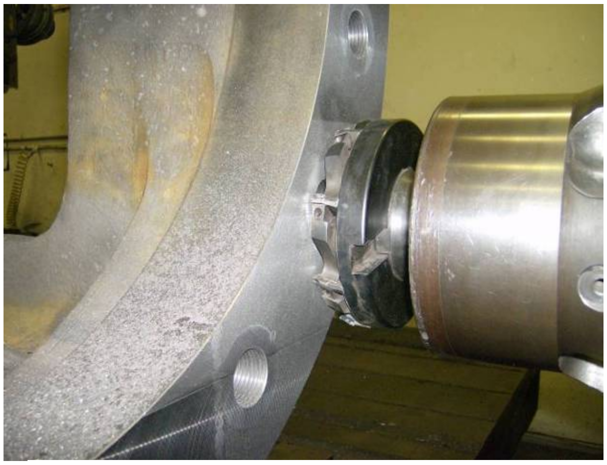
The original holes were drilled and tapped with a special FT tap

The broken out areas were milled out to accept the new steel plates and tapped to accept the blind Full-Torque thread inserts

New sections of steel plate fit in and locked in place with FT thread inserts, the joint lines were stitched for strength and high pressure seal

The stitching continued until all edges were completely finished

Additional inserts were installed to repair other damaged stud holes



The face was machined flat to finish the repair

The same concept was used to fill in additional pulled out stud holes

A compressor frame also suffered from pulled bolt holes and was repaired on-site with the same process

Stitching around the patch

The repairs were machined flush

13. Preventing bolt and stud hole failures

The method of machining a nipple on the bottom of a stud and then torquing them in to keep them from rotating has proven to result in premature failures of the threaded holes in cast iron. If one stud breaks, the load is transferred to the adjacent studs and if the broken stud is not replaced immediately additional studs will begin failing. Every pound of torque placed on a stud when bottomed into a hole requires that many pounds of torque to be subtracted from the nut.

When a stud breaks it frequently fails below the surface where the maximum load is located. When this happens, a large section of cast iron is frequently pulled out with the upper part of the stud starting where the stud broke.

It has become a common procedure with many customers to install Full-Torque thread inserts into all bolt and or stud holes in compressor castings during overhauls even if they appear to be in good condition to prevent future failures and increase their strength and durability.