REPAIRING DAMAGED DIE STEELS AND CASTINGS

Gray iron, as well as iron alloy and steel die castings occasionally become cracked or broken. Typical root causes of the failure are careless handling, diesetting shut height errors and multiple part in die problems due to part ejection failures. Such cracked or broken castings must be repaired quickly. Most dies subject to this type of damage are used to produce large irregularly shaped parts used in the automotive and appliance industry.

Quick Repairs are Often Necessary
Dies with large special castings are usually a one of a kind item. The patterns are almost universally of the lost Styrofoam type since only one casting is required. This type of pattern is destroyed during the casting process. If a replacement casting is needed, a new pattern must be made. Typical casting weights are from a few hundred pounds (Kgm) to 20 or more tons (20 T).

A Large Die Casting Repaired without Welding

Figure 1. A large die for trimming formed irregularly shaped sheet metal parts. The die is shown in the inverted position so the die shoe resting on wood timbers is actually the top shoe. Note the steel plate added to reinforce the top of the shoe. In addition, there is a tie-rod running the length of the die to hold two broken halves in compression. 

SUPERBOLT, Inc.
Welded Vs Non-Welded Casting Repairs

Whenever a mishap results in a broken die casting, usually a decision must be made quickly and a plan acted upon to start repairs at once. Factors to consider include:

1. The base metal of the casting and its suitability for electrical arc welding or oxygen fuel gas brazed repairs.

2. Properly done, welding and brazing processes require careful preheating, post heating and often some remachining and refitting to correct for distortion. All of this takes time if done properly to insure a lasting repair.

3. Is the nature of the damage such that mechanical repairs such as bolting the die shoe to a backing plate, the use of tie-rods and/or repair plates fitted into machined pockets known as a Dutchman may be used?

4. Is a new casting required to replace the damaged one even if emergency repairs are possible?

5. The thickness of the casting walls and webbing may dictate the repair procedure, especially in lightweight designs.

Discussion of Decision Making Factors

The wall thickness and size of reinforcing ribs of the casting are important factors. Heavy sections permit long lasting mechanical repairs that would be difficult in a lightweight cost and weight saving design style casting. However, the lighter casting is easier to preheat and requires less filler metal than a casting with thick sections.

The lead time for making a large new casting in an emergency is approximately two weeks minimum if the necessary drawings for making the pattern are available. Usually considerable machining is required on a large casting. In addition, parts such as wear plates and other details must be attached and fitting to existing parts accomplished. Finally, the assembled die must be tried out to insure that it functions properly and that the parts produced meet all specifications.

If a successful mechanical or welded repair can be made with certainty, there is little reason to order a new casting. Mechanical repairs in dies subject to diesetting errors or multiple part damage may fail in the event of an overload. However, the bolts, tie-rods and Dutchman used to make the original repair will tend to stretch or break limiting further damage to the casting. Thus, if the cause of the failure should reoccur, as is often the case, it is much easier to repair the second time. This is typically much more easily accomplished than fitting a new shoe casting even if one is ordered as a spare when the previous failure occurred.
Example of Successful Mechanical Repair Techniques
Figure 1 illustrates three repair techniques useful for the repair of broken cast die shoes. As shown in the figure, the die is inverted or in an upside down position on the floor. The die is a trimming die. Dies of this type are used for trimming formed irregularly shaped sheet metal parts. Any number of reasons could cause this type of casting failure. Typical causes of the failure are careless handling, diesetting shut height errors and multiple part in die problems due to part ejection failures.

End View of Tie-Rod with Steel Plate to Spread Load

Figure 2. End view of tie-rod tensioned with a patented SUPERBOLT ™. Note the use of a thick steel plate to spread the load evenly. SUPERBOLT, Inc.

Types of Repair Techniques Employed in Figure 1
Three casting repair techniques are shown in Figure 1. These are:

1. Tie-rods tensioned with SUPERBOLTS ™ on both side through openings in the casting ribs.

2. A securely attached steel plate covering the entire area of the upper die shoe.

3. A Dutchman applied to the casting wall to assist in holding the break securely together under load.
Preparation of a Cracked or Broken Casting for Mechanical Repair

Gray cast irons vary greatly in tensile strength. They are produced in ASTM classes 20, 25, 30, 35, 40, 50 and 60 with each class corresponding to the minimum tensile strength in thousands of pounds per square inch (ksi). This range spans the metric equivalent tensile strength range of approximately 138 MPa to 414 MPa.

Other cast die materials include the ductile and nodular irons as well as steel. These materials as well as the higher class gray irons are subject to elongation prior to fracture. This elongation, especially in the irons tends to be localized in the area of the fracture but can cause substantial distortion of the casting in some cases.

However, in most cases, the stresses leading to failure are concentrated in one or more areas of the casting. There are two casting failure modes each requiring a different repair preparation. These are:

1. Repeated cyclical strains that initiate and result in failure through gradual crack propagation. In these cases, there is negligible or very slight elongation or distortion in other than the area of failure(s).

2. In the case of a sudden exceeding of the yield and ultimate tensile strength of the casting material, as evidenced by a rough tearing of the metal is localized to one or more areas. These rapid failures are likely to result in some deformation of the casting, especially in areas near the fracture.

Determining Casting Distortion

If elongation or distortion of the cracked or broken casting is suspected, it should be placed on a surface plate to permit measurements of shoe flatness and correct dimensions. Large heavy castings may be tested for fit as well as dimensional accuracy by placing the parts on the bed of a large milling machine table and determining how accurately they nest or fit together.

If the crack is a gradual one extending part way through the casting, one of the several mechanical repair methods discussed may prove suitable to prevent further crack propagation and prevent movement in the cracked area known as breathing.

In sudden overload fractures there are usually projections of torn metal that can prevent the casting from being fitted back together for mechanical repairs unless they are carefully ground away. In lower grade gray irons, there is usually a clean fracture with little elongation. Carefully grinding the high points away may provide a proper preparation for a mechanical repair. However, if there is elongation or distortion of the casting, hand-grinding process often is the best way to fit the broken pieces together in correct alignment. Skillful work is required to fit the parts together correctly. This work is best done by hand using Prussian or spotting bluing to achieve a close fit. Because of the irregular fracture paths, machining is not a good way to fit the pieces together.
Tie-Rod Materials
The most commonly used steel shafting for making die repair tie-rods is AISI 1018 cold drawn steel. This material has a yield strength of approximately 45 ksi (310,185 MPa) depending on the extent of cold working. Generally, fasteners including tie-rods are pretensioned to no more than 70% of yield strength.

Other materials are available with higher tensile strengths such as cold drawn AISI 1040 and 1140 material having tensile strengths in the 75 to 90 ksi (552 to 665 MPa) range. Small diameters tend to be cold worked more severely and therefore attain higher tensile strengths. Other readily available materials include AISI 4140, which can be heat treated to achieve yield strengths in excess of 140 ksi (965 MPa).

The maximum straight line compressive loading is approximately three times the tensile strength for class 20 material and twice the tensile strength for the class 60 material. Therefore, tie rods can be preloaded to high tensile forces to hold a broken casting in compression. However, a substantial reduction in preload must be allowed if there are ribs and voids which can deflect or fail under compressive loads.

Close-up of SUPERBOLT™ Tie-Rod Tensioner

Figure 3. Close-up view of the SUPERBOLT™ tie-rod tensioner shown in Figure 2. These are used to pretension a tie rod on each side of the die shown in Figure 1. Note the tightening sequence marked on the tie-rod end. SUPERBOLT, Inc.

Using Tie-Rods to Hold Broken Castings in Assembly
Heating could pretension the example shown in Figure 1 with a large oxygen fuel gas torches using engineering formulas similar to those used for pretensioning press tie-rods. This could prove workable in this case because the tie-rod is exposed for heating. However, an error resulting in overtensioning could break the end ribs.

**Sectional View of A SUPERBOLT™ Tie-Rod Tensioner**

*Figure 4.* Cut away view of the SUPERBOLT™ tie-rod tensioner shown in Figures 2 and 3. Note the placement of hardened steel shim plate under the tensioning device supplied by the manufacturer. *SUPERBOLT, Inc.*

The following data is based on a linear coefficient of expansion for carbon steel of $12 \times 10^{-6}$ per °C. Carbon steel expands approximately 0.00000667 inch per °F, which is

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0.00008 inch per foot per °F. To attain the preload of 20 ksi (138 MPa) typically used to pretension press tie-rods the tie rod would need to be uniformly heated 105 degrees Fahrenheit. This would expand the tie-rod 0.0007 inch per inch, which is 0.0084 inch per foot. Uniform heating of long die repair tie-rods is difficult at best.

Other heating approaches can be used if the amount of pretension preloading is accurately known in advance. The preload must be enough to securely hold the broken casting together without causing excessive deflection or any risk of breaking ribs or thin sections. The rod can be heated to a higher temperature than necessary and a conventional nut used to hold the casting in the correct compression by turning the nut a calculated number of degrees or distance. This procedure is very unforgiving, especially when a heated tie-rod must be placed in a long drilled hole through solid metal.

To accurately control the amount of preload and add stiffness to the assembled die, a tubular spacer may be placed around the tie-rod. The spacer should have 1.5 times the area of the tie-rod. In addition to adding stiffness, the spacers will reduce the alternating load in the tie-rod thread. The tubular spacer must be made slightly longer than its final compressed length. While the amount of compression can be estimated using engineering data, some cut and try work is usually required. Providing a short section of tubing on one end of the spacer is a good idea. It can be easily removed for shorting during fitting saving time. In the event that a longer spacer is needed, it is easy to supply and fit one.

**Die Repair Using the SUPERBOLT™ Tie-Rod Tensioner**

Figure 1 is an overview of a large die for trimming formed irregularly shaped sheet metal parts. The die is shown in the inverted position so the die shoe resting on wood timbers is actually the top shoe. Note the steel plate added to reinforce the top of the shoe. In addition, there are two 3-inch (76.2 mm) diameter tie-rods running the length of the die on either side of the upper shoe to hold a 0.135-inch (3.492 mm) crack in compression.

As shown in Figures 2 and 3 the SUPERBOLT™ is used much like a hydraulic tie-rod nut to pretension the tie-rods used to hold the broken die shoe together. However, unlike a conventional tie-rod nut no heat or hydraulic pressure is required to pretension the device. Figure 4 illustrates an isometric cut away view of the SUPERBOLT™. The screws known as *jackbolts* are tightened in a specified sequence with an accurate torque wrench.

The amount of actual tie-rod tension can be applied to a close tolerance by knowing the amount of torque applied to the jackbolts. It is important to use the lubricant specified by the manufacturer in order to achieve a known value of jackbolt torquing tension.
An important feature is being able to adjust and easily remove the die casting repair tie-rods. Tension can easily be checked and adjusted in the production press. The SUPERBOLTS™ are accessible. Be certain that proper lockout procedure is followed when working in and around power presses.

The repair illustrated did not require the full the full torque capacity of the SUPERBOLTS™ and the tie-rods. The final torque value can be applied in steps until full crack closure is assured under normal operating forces as the press cycled. The use of SUPERBOLTS™ for tensioning die repair tie-rods has been used a number of times with successful results. The cold tensioning method over the uncertainties of heating tie-rods to obtain tension has many advantages.

**A Dutchman Bolted to a Casting to Clamp a Crack**

![Figure 5](image)

**Figure 5.** A steel plate having projections on each end that mate with milled pockets on either side of a crack in a die casting. The device retained with screws is a Dutchman. It is shrink fitted in place by heating and tensile preload develops as it cools to ambient temperature.
Adding Steel Plate to Reinforce Broken Die Shoes
Figure 1 illustrates a steel plate approximately two inches (50.8 mm) thick bolted to the cracked upper die shoe (shown in inverted position). A safety feature of this portion of the repair is that the die shoe has bolt tie down slots that line up with those of the broken shoe. This permits the bolts that attach the upper die shoe to the press ram to hold the sandwiched plate and shoe assembly in compression.

The plate should also be doweled to the pieces of broken die shoe for locational fit only. Avoiding lateral movement of the plate relative to the shoe pieces cannot be assured by the use of dowels alone. Dowels are for locational reference only.

If the clamping force of the screws which prevents movement by friction between the shoe pieces and the plate is insufficient to prevent movement, then rectangular keys should be used in tightly fitted machined pockets.

It is important that the press ram impart no lateral movement to the upper die. This is especially true of one that has been repaired. This problem can occur if the press is not aligned properly. This is especially a problem on twin end drive geared presses that are out of time.

Applying Clamping Force to a Crack with a Dutchman
Figure 5 illustrates a clamping device for repairing die castings known as a Dutchman. As shown it is shrink fitted with heat. The same thermal expansion formulas discussed earlier are used to determine the correct preload.

A seldom-used alternative is to provide a calculated draft angle in the milled pocket and mating projections to obtain the required preload without the application of heat. This procedure also permits easier removal.

It is suggested that additional screws can be used to fasten the Dutchman in place, especially if the cold process is used. A staggered screw pattern should be used to spread the load and avoid further weakening of the casting.

Other Useful Cold Crack Repair Techniques
There are several methods of inserting repair blocks into holes machined into pockets in the casting at the location of a crack or fracture. This is often accomplished with hand drills and chipping hammers used to cut the pocket. Steel blocks are then fitted into the pockets. The repair blocks are firmly held in place to repair the fracture by threaded studs that are retained by drilling, tapping, screwing in place and peening for retention at the juncture of the repair insert and the pocket.

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2 The term Dutchman as used here does not refer to a resident or person from the Netherlands nor a male German of the Teutonic race. In United States technical applications, the term has been used for at least 150 years to refer to a mechanical repair or plate originally used to mend a crack in a stone slab. The application to the repair of a casting by a similar means is a widely accepted use of the term.
Another method makes use of many screws placed directly in the break in the casting at an angle to pull the crack together. Since this is a specialized skill requiring considerable skill and experience to carry out successfully, extensive specialized repairs of this type are best left to contracted outside experts. Unless die castings are broken very frequently, the necessary skills are not likely to be learned by many repair persons. As a common sense rule, careless practices that damage die castings and the care, patience and skill needed to carry out successful repairs of this type is unlikely to be found in the same shop.

A plant culture that tolerates carelessness and the fostering of highly specialized repair skills is a contradiction in expected management practices. The repair providers who specialize in casting repairs of this type are usually willing to do the work at the client’s plant on short notice in an emergency.

### Repairing Broken Castings by Welding and Brazing

#### Electrical Welding Considerations

Cast iron dies can be welded, but the method of application of the weld differs from that for steel because cast iron melts at a lower temperature. Nickel welding alloys with lower melting temperatures are recommended for underlay on all cast irons.

Generally, after careful preparation involving grinding out the area to be repaired and preheating the work, a deposition of nickel alloy weld is made followed by the desired welding material required to obtain the needed surface properties. Where a very high-strength bond with the cast iron is needed, the iron can be studded with mild steel threaded inserts. An easy way to do this is to drill and tap the iron casting for mild steel cap screws. The screws are tightened and then cut off flush with a cold chisel.

It is very important that alloy steel screws are not used because a brittle weld may result. This method is excellent when repairing old, oil-soaked cast iron.

#### Repairing Iron Castings by Brazing

Large broken iron die castings can be repaired by brazing. Preparation by machining or grinding is required to provide a large area for adhesion of the braze material. Careful pre-heating and post-heating is an absolute necessity. Charcoal is an excellent fuel source for occasional repairs on large castings. Brazed repairs are especially useful on lightweight cast die shoes that may not be easily or permanently repaired by mechanical means.

#### Worker Concerns When Brazing Large Work.

The repair of a large casting by brazing may take several days of around the clock work. To avoid both human and mechanical stresses, it is often required to have two welders working at one time on opposite sides of the casting. A second pair of welders is resting and alternate places periodically so that the work is carried on continuously.
Proper protective clothing and respirators is essential for this work. Metal fume poisoning is a problem with brazing jobs. Zinc is a necessary constituent of the brazing filler metal and fumes are usually the main health concern. However, minute amounts of cadmium in the brazing filler metal are an especially worrisome impurity from a worker health standpoint.

It is common to deposit several hundred pounds (kg) or more of filler metal to repair a large casting. To add strength, the braze may be built up above the surface of the casting and extended to each side of the casting surface provided mechanical interference in the functioning of the finished work is not a problem. Peening of the filler metal may be required to relieve any residual tensile stresses that may develop upon slow cooling of the work.

**Electrical Die Steel Welding**

**Base Metal Considerations**

When the base metal for an intended application is carbon steel, there are no particular restrictions in the choice of an alloy tool steel welding material. There are, however, some restrictions with other base metals, including stainless steels. Tool steel welding requires taking precautions similar to those necessary with any other type of welding process to prevent cracking of the base metal during heating and cooling.

All base metals with carbon content higher than 0.35% should be preheated and postheated to decrease brittleness in the base metal near the heat-affected zone. High-carbon alloy steels such as air-hardening tool steels are more difficult to weld because of the likelihood of cracking. Tool steel welding is used successfully in most instances for the repair of tools made of air-hardening steel. Hot extrusion tools are a notable example of successful use of this type of repair.

**Types of Electrical Welding Used to Repair Dies**

Basically, three welding methods are used for die repair. The American Welding Society classifies them using the following lettering system:

1. SMAW - Shielded metal arc welding or stick welding.
2. GMAW - Gas metal arc welding, also known as MIG.
3. GTAW - Gas tungsten arc welding, also called TIG or heliarc welding.

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The SMAW or stick welding is the most popular method since it is extremely versatile. This method also offers a wide selection of filler metal analysis.

The GMAW or MIG process is usually superior in terms of speed and quality, however. The filler metals are available as either solid or tubular wire. The tubular wire filler metal offers the widest range of alloy selection.

The GTAW or TIG process offers the operator optimum control and inclusion-free welds. The selection of bare metal filler rods is somewhat limited.

**Die Welding Applications**

In die welding, wear resistant alloys applied to the surface of dies increases service life, avoid down time, or to rebuild or repair dies damaged in service. Welding is useful to correct machining errors, and to increase the wear resistance of die surfaces. Varying degrees of hardness, toughness and wear resistance are available in welding alloys depending upon the application.

**Die Welding Materials**

Tool steel welding materials are normally heat treatable alloys. Alloys for SMAW (stick) welding have a wire core covered with a flux coating, which may also contain alloy constituents, including rare earth elements. Alloying elements in the flux coating pass across the arc and form a homogeneous weld deposit.

GMAW arc welding alloys for semi and fully automatic MIG welding are available as tubular and solid wire products. This process requires an external shielding gas. Additional alloying elements can be incorporated in the tubular flux. Solid MIG welding wire does not provide additional alloying.

GTAW (TIG) alloys are made of bare wire cut to 36 inch (914 mm) long. Small diameter sizes are available that permit the operator the utmost control for precise build-ups and contours. All basic tool steel alloys are available.

The tool steel groups most commonly repaired by welding are water, oil and air hardening steel. The degree of welding difficulty is dictated by the alloy content of the base metal. Usually steels with higher carbon contents require higher preheats before welding, more care during welding and consideration of tempering temperatures after welding.

**Welded Trim Edges**

The dies used to trim large irregularly shaped drawn panels are made of gray cast iron. The cutting steels on the punch shoe are either of cast alloy steel or wrought composite tool steel construction. A. gray iron casting called a post is mounted to the lower die shoe. The part to be trimmed is placed on the post. The post has a milled ledge or pockets into which the tool steel lower trim inserts are fastened as shown in Figure 6.
Conventional Tool Steel Trim Die Post Section Insert

Figure 6. A sectional view of a conventional cast iron trim die post having a tool steel insert fitted into a milled pocket. *Smith & Associates & MPD Welding, Inc.*

An alternative construction method is to eliminate the post inserts, and provide a tool steel cutting edge on the gray iron post by welding as shown in Figure 7. Success in producing a cutting edge by the welding method depends upon following strict procedures in preheating, welding materials, welding technique, peening and cooling.

A U groove is first ground or machined around the post. This is readily done on the CNC profile mill used to machine the finished contour of the post. A vertical land is provided as a reference of the trim line location for finish grinding after welding.

To avoid producing a layer of brittle white chilled iron under the weld, the casting is preheated to 750° F (400° C). A good method is to place the casting on a special table fitted with a number of small gas burners. To conserve heat, the casting is covered with mineral fiber blankets except for the area being welded.
A Welded Trim Edge

Figure 7. A welded trim edge built up on a cast iron trim die post. *Smith & Associates & MPD Welding, Inc.*

Temperature control can be provided by a thermocouple probe, which can also automatically regulate the burners. Many skilled operators control the burners manually and determine the heat with temperature indicating marking sticks.

Two types of weld are deposited. A layer of unique nickel alloy weld is deposited first to act as a buffer for the hard weld material that forms the cutting edge. Materials commonly used include AISI-S.7, H12 and H19.

The buffer layer serves to prevent excessive carbon and other elements from the gray iron mixing with the air hard weld and changing its properties. The nickel alloy layer also provides a good bond with the casting.

The buffer layer is carefully deposited on one small area at a time. To avoid the production of white chilled iron, several passes are deposited in sequence. Each successive pass serves to anneal the iron under the weld.
To relieve the tensile stress that would occur upon cooling, the weld metal is upset by careful peening with a pneumatic hand tool between each pass. The finished weld must be as stress free as possible, although slight compressive stresses are not considered harmful.

The final cutting edge is built up with air hard weld and after cooling to room temperature is carefully tempered.

If trim changes or repairs are needed, the casting should be ground out to expose sound metal and the initial welding procedure including preheating, and slow cooling followed. Small chipped spots can be repaired by TIG welding and peening as an emergency measure although the quality of the repair is compromised.