

Inspecting Welds in Rail

While visual examination is the railroad industry's most common inspection method, railroads also rely on a variety of other NDE technologies

BY BERTIL EKLUND AND BOB CROCKER

Railway rail is subjected to complex stress patterns throughout its working life. As wheels pass along it, they introduce stresses of varying degrees dependent on the weight of the axle. In addition, there are many mechanical features, such as insulated rail joints, switches, crossings, and signaling attachments, that result in holes; changes in cross section; and welds. These factors, combined with environmental effects of temperature, water, ice, and a wide range of contaminant fluids, lead to a situation in which a variety of defects can initiate and grow while the rail is in service.

One of the key areas where there are the most complex interaction of stresses and geometry in the rail is at bolted joints. The nature of a bolted joint is such that there are a number of holes drilled in the web of the rail, and then joint bars (called fish plates in the U.K.) are used to keep continuity of stress from one section of rail to the next. Every one of these has the potential to introduce a stress riser that can enormously increase the local stress, leading to rapid crack growth and failure. For this reason, there has always been a desire to remove bolted joints from track; this is achieved through the process of rail welding.

There are a number of methods for welding the ends of rail to form a continuous "string." The oldest and most common is aluminothermic welding (the thermite welding process). This is followed by various forms of manual arc welding and, most recently, the technique of flash welding. A brief description of these welding methods follows (see *PWI British Railway Track Handbook* for detailed descriptions).

The thermite welding process essentially makes use of molten steel to fill the cavity between two rail ends to fuse the ends together as the steel solidifies. An exothermic reaction in a mold placed over the cavity melts the steel. At the appropriate moment, it is allowed to drain into the cavity, thus forming the bridge between the two rail ends, where it is effectively "cast."

Arc welding is carried out by an operator filling the cavity between the rail ends using many passes with manual welding rods to fill the root opening to fuse the ends together.

Flash welding differs from the other two methods because there is no requirement for any material to be used in the process other than that of the rail itself. A powerful electrical current creates arcs between the rail ends as they are touched together. These arcs cause the rail ends to heat up and become semi-molten, at which point the ends are pushed together, causing them to fuse. On cooling, the rail ends are joined without the introduction of any filler metal.

All these techniques can introduce defects into the rail. The great majority of these occur at the weld interface between the weld metal and the base metal, with a smaller number in the body of the weld metal itself.

The task of the inspector is to detect and classify any defects,



Fig. 1 — An example of incomplete fusion.



Fig. 2 — An example of porosity.

preferably at the time at which the weld is made. A great deal of statistical evidence shows that a weld is most likely to fail shortly after it was formed, or not at all.

Weld Defects

Inspection methods fall into two broad classes: visual inspection and instrumented techniques. The second category includes dye penetrant and magnetic particle inspection, ultrasonics, and radiography.

The most serious defect is incomplete fusion. This is where the new material introduced during the welding process does not fuse, or adhere, to the rail ends — Fig. 1.

BERTIL EKLUND (beklund@sperryint.com) and BOB CROCKER are with Sperry Rail International Ltd., Derby, U.K.



Fig. 3 — An example of a hot tear.

Another common problem is porosity, which occurs because the material that the mold is made of, normally sand, is moist when the weld is made and generates gas bubbles as the molten steel solidifies — Fig. 2.

A more recent defect type is that of the hot tear. This occurs when tensile stresses are applied across the rail weld before the steel has solidified, which results in a pulling apart of the weld material inside the volume of the cast material — Fig. 3.

All these defects are essentially internal to the weld. They are not readily detectable from the outside unless part of them actually reaches an external surface. If this happens an inspector can see the effect as a surface blemish.

Another important point to note is that once a weld is established in the rail and has been in service without failing, it can then be treated as plain rail with respect to further failure mechanisms. Therefore, the defect types associated with normal mid-span rail apply equally to rail welds as far as inspection methodologies are concerned.

Inspection Methods

Visual

By far the most important inspection of any rail weld is the visual inspection carried out by the welder at the end of the welding operation. Either the welder, or a designated inspector, must carry out a detailed visual examination of all the external surfaces of the weld to determine if any of the defect types identified previously are present as surface-breaking features. Each railway organization prescribes the way in which the weld must be examined and reported, for instance, the use of a mirror to examine under the rail foot. Viewing of any external defects normally triggers the requirement to carry out a further test of some sort.

Dye Penetrant

This technique “decorates” the surface of the rail to increase the visibility of any surface-breaking cracks or other features. It works by coating the rail with a dye formulated to penetrate cracks so that when the majority of the dye is removed from the surface, the dye that remains trapped in the cracks becomes readily visible, thus highlighting the presence and whereabouts of the crack.

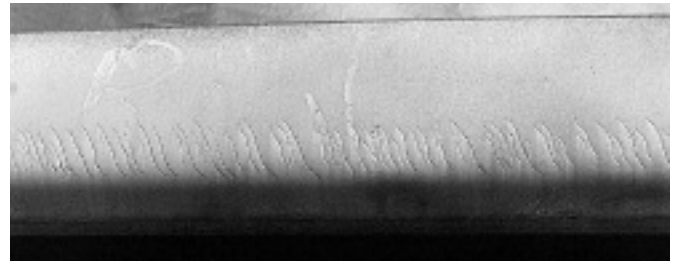


Fig. 4 — Surface-breaking crack “decoration.”



Fig. 5 — Radiograph of a defective weld.

Magnetic Particle

This is essentially similar to dye penetrant in that it is a technique that “decorates” the rail surface to highlight the whereabouts of any crack. The rail is magnetized and then coated with a powder or liquid containing magnetic particles. There is an enhanced magnetic field where there are any surface-breaking features and these are shown by the presence of particles when the residual bulk of the powder or liquid is removed from the surface — Fig. 4.

Radiography

Welds in railway rail have always been regarded as ideal candidates for inspection by radiography because of the relatively thick steel sections and complex geometry of the specimen — Fig. 5.

However, in practice, it has proved prohibitively expensive for the industry as a whole to adopt this method. X-radiography needs a powerful electrical generator to provide sufficient penetration and radioactive methods require a relatively powerful isotopic source. These all bring very difficult environmental and health and safety issues into play when used in the field. Furthermore, it has proved difficult to get correlation between the results of radiographic examination and the mechanisms of failure. Several studies found that radiography can be used to show that virtually all welds have some defects but, in practice, very few fail.

Ultrasonics

Ultrasonic techniques are used wherever railways are operated. They are used mainly for inspection of plain line and bolted joints. There are techniques that have been developed specif-



Fig. 6 — The GULS equipment for weld inspection.



Fig. 7 — Ultrasonic walking stick.



Fig. 8 — High-speed ultrasonic test vehicle.

ically for weld inspection, but it must be stated that none of the techniques currently in use inspect within the cast material of the weld. They are all used to determine the quality of the fusion faces.

There are many variations on the theme of fusion face examination, but essentially they all attempt to examine the fusion faces at all points in the cross section of the rail. Most other ultrasonic rail inspections concentrate only on the head or web, but weld inspection has to pay as much attention to the rail foot as it does to any other part of the cross section.

Manual Inspection with Hand Probes

The vast majority of ultrasonic inspection of rail welds is carried out by skilled operators using handheld transducers. For some parts of the cross section, two transducers are used together in a technique in which one acts as the transmitter and the other as the receiver of ultrasound that is reflected off the internal fusion faces. The operator is trained to recognize signals that represent defects such as incomplete fusion or porosity in the fusion face. A single transducer is used for other parts of the cross section, and in those cases, the transducer acts as both transmitter and receiver.

In all cases, inspection is relatively slow and the operator requires considerable training, skill, and experience to properly inspect the welds. This presents difficulties in three ways: firstly, time on track for an operator is costly and, if the line is open, increasingly dangerous. Secondly, the cost of training and supervision while an operator is gaining skill is becoming almost prohibitive. Finally, the whole process is subjective because there is no direct record of the inspection, only the notes made by the operator. There is no direct evidence of calibration of the equipment, or of the care with which the inspection was carried out. The process relies entirely on the integrity of the operator.

This all leads to a situation where most welds are never inspected unless a defect has been detected during visual inspection.

Manual Inspection with a Probe Rig

Some railway organizations use the same transducers that are used in a hand examination but place them in a so-called “tandem rig.” The objective is to introduce some consistency to the manipulation of the hand probes by removing manual manipulation from the operator’s control. However, this can only be used on certain parts of the cross section and some areas remain under the control of the operator. Consequently, the same considerations apply to this method in respect to inspection integrity.

Instrumented Ultrasonic Inspection

In an attempt to remove the subjectivity of operator-based ultrasonic examination of welds, several railway organizations are developing new ultrasonic techniques to inspect the whole of the weld cross section without the need to use handheld transducers.

The most highly developed procedure at present is known as guided ultrasonic wave inspection. This makes use of a previously somewhat undeveloped branch of ultrasonics called Lamb waves. These types of ultrasonic vibrations cause the whole specimen, for instance rail containing a weld, to vibrate. By measuring and recording the variation of vibration patterns using sophisticated computer techniques, the developers can now identify and classify the various defect types within the weld. In the U.K. this is being developed as a piece of equipment known as GULS — Fig. 6.

Currently this is still a “spot” technique in which equipment has to be situated on the rail, thus requiring access to the line. However, it does bring the potential for complete cross-sectional examination, but with an auditable record (thus improving on the current ultrasonic techniques) but without health, safety, or environmental problems (thus overcoming the difficulties associated with radiography).

Plain Line Ultrasonic Inspection

As stated earlier, once a weld is in use in track it is treated as plain line. There are several techniques used to inspect plain line but the main ones are the use of angle beam ultrasonics mounted either on “walking sticks” (Fig. 7) or on various vehicles — Fig. 8.

Conclusions

There are a number of defect types that occur in welds in rail. These can all be detected in principle but there are practical difficulties with all the methods in use brought about by the railway environment. Consequently, the most common, and mandatory, inspection method is visual inspection with various other inspection methods required if visual inspection reveals any problems.

None of the methods in routine use produces automatic, auditable records of inspection integrity.

Techniques are in development for examinations that would reduce the requirement for skilled operators and produce complete records of the test.

Once a weld is in service it is inspected as equivalent to plain rail by all the methods in routine use. ❖