# Production Processes To Yield Superior Rail Steel

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**Today is a time of great technological change in rail production. Improvements have been noted in basic rail oxide, sulfide, and hydrogen controls, as well as surface inspection techniques and the use of lasers and computers for rail flatness, straightness, and geometry. Improvements in microstructure control and its effect on wear are discussed along with some of the latest developments in both off- and on-line continuous mill hardening. Finally, the overall package of such improved rail offered over a hardness range of 300 to 400 Brinell Hardness Number (BHN) gives the user a wide range of choices. It is suggested that this freedom of choice will be characteristic of rail in the next decade.**

Finished rail must give a satisfactory life over a suitably long period. Wear resistance can now be built in, but before full wear performance can be achieved the rail must be capable of limiting local stress raisers connected with microinclusions, microhydrogen, surface defects, surface flatness, and geometry.

The production of basic rail to the required standard of consistency will be reviewed and the processes capable of promoting the desired wear properties will be considered in this paper.

## BASIC RAIL

### Raw Material and Bloom Production

For consistent results it is better to begin with standard raw material. For that reason liquid iron from a modern blast furnace is the ideal starting material. This iron can be pretreated before basic oxygen steelmaking. In 250-tonne vessels, the iron is blown to 0.1 percent carbon steel in around 40 min. Gas stirring and the addition of low aluminum bring the ladle almost up to rail steel chemistry. Vacuum degassing and further trimming stations allow final chemical control, so that 98 percent of rail steel can be produced within a range of 0.05 percent carbon and 0.10 percent manganese. No aluminum is added directly, which ensures steel free from angular, brittle aluminous stringers.

The degassed and trimmed steel, temperature controlled to ±10°C, is then continuously cast under fully tubed and submerged conditions. Sequence lots of around 2,000 tonnes are typical. These batches are placed into 2,000-tonne insulated boxes while still at 600°C. With a cooling rate of less than 1°C per hour, the blooms are given a second hydrogen treatment for a period of 3 to 5 days. Blooms are removed and are available for rolling to rail without any need for surface correction.

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### Internal Discontinuities

At this early stage decisions have already been made that preset oxide inclusion type, sulfide amount and distribution, and hydrogen preflake presence.

#### *Oxide*

To date, British Steel Corporation (BSC) has developed a special low-aluminum process in which no direct additions of aluminum are allowed. Figures 1 and 2 show the oxide levels obtained. In this process, the main choice is oxide type—either aluminum silicate or manganese silicate (Figure 3). Whichever oxide is used, the level must be minimal.

#### *Sulfide*

Sulfide has a generally positive effect in helping to reduce hydrogen problems but a negative one on toughness and wear. A balance has to be found. BSC uses a typical sulfur range of 0.01 to 0.015 percent at the moment, but development work is continuing at BSC Swinden Laboratories.

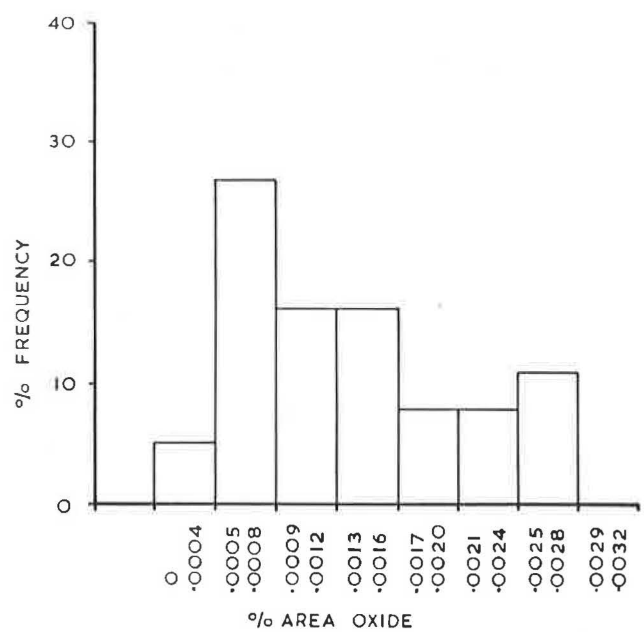


**FIGURE 1 Distribution of percent area oxide in rail head.**

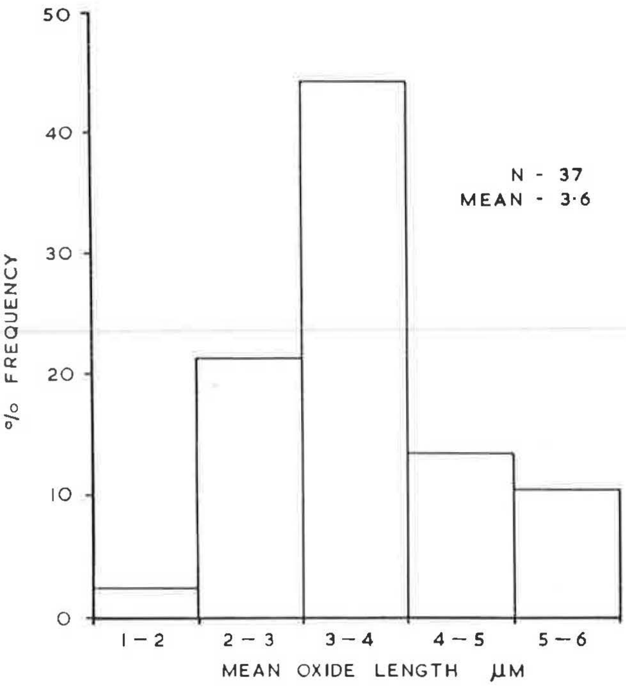


**FIGURE 2 Distribution of mean oxide length in rail head.**

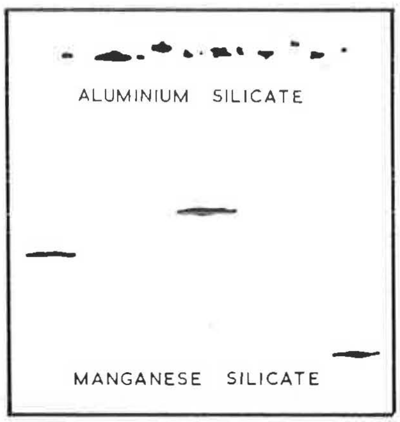


**FIGURE 3 Oxide inclusion types.**

*Hydrogen*

The decisions regarding hydrogen are difficult. Assuming that a manufacturer avoids the actual production of detectable flakes, it takes from 3 to 15 years for microflakes to develop by fatigue into measurable defects. The testing span is therefore extremely long, and, which is still worse, actual hydrogen tests are not exact. Figure 4 is a graph showing hydrogen requirements typical in the rail industry. The lower dashed line shows where hydrogen damage—not flakes—has been observed under laboratory test conditions. In view of this and while research is continuing, BSC uses a double hydrogen treatment, that is, full vacuum degassing and full bloom cooling. The average hydrogen in the finished rail is around 0.5 ppm.

## RAIL PRODUCTION

Blooms are reheated and rolled into rail. At this stage there are two main options that produce the correct wear resistance. These will be discussed later.

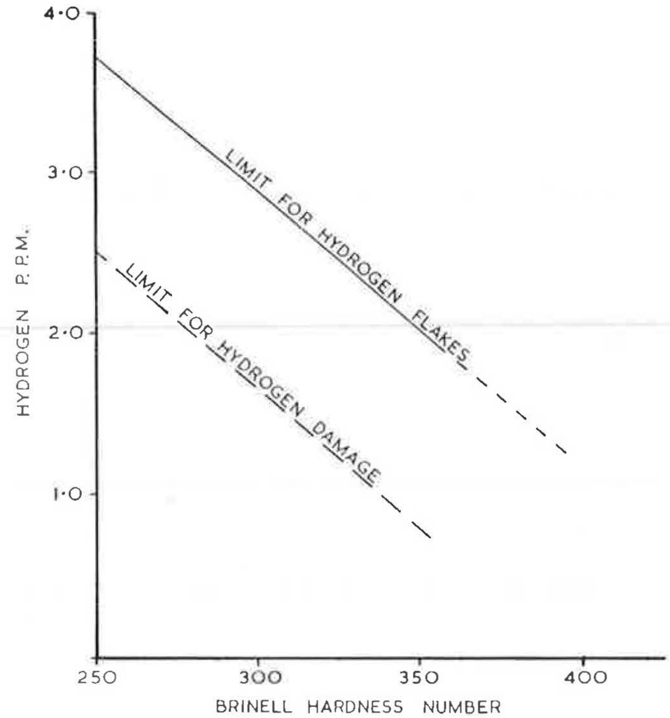


**FIGURE 4 Hydrogen requirements typical in rail industry.**

Rails are produced in multiple lengths to improve straightness control. A single plane roller straightening machine straightens the rails. Immediately after leaving the machine, the rails are checked for inclusions, surface defects, and surface flatness. Equipment is being installed to check straightness and section geometry.

### Inclusion Testing

All rails are checked for microinclusions by a 16-probe ultrasonic machine (Figure 5). The number of rails rejected is

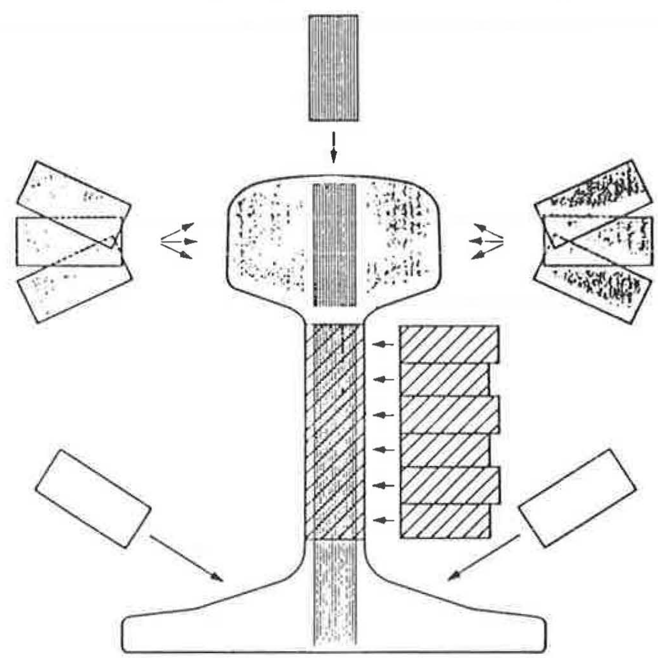

**FIGURE 5 Ultrasonic testing.**

negligible, which should be a comfort to travelers. Background inclusions are so small that ultrasonic machines are now of little use. Consequently, although it is only 2 years old and one of the best available, this latest machine has come at a time when steelmaking advances have almost eliminated the need for it.

### Surface Quality Assessment

Mirror-assisted visual inspection under ideal light conditions has been used for many years, but rail standards are now such that mirror inspection is less acceptable, for two main reasons:

1. Less than 0.25 percent of rails contain any form of steelmaking defect. It is therefore difficult for an operator to maintain the concentration required to find 1 defective rail in 400, particularly because for any individual operator the ratio is 1 rail in 2,400.
2. Modern railmaking requires such defects that are present to be measured for manufacturing control purposes.

BSC has developed fully automatic eddy current inspection for the foot of the rail, and during 1987 newly developed railhead testing will be installed. The basis of the system is the measurement of magnetic eddy currents set up in the rail surface by a coil carrying an alternating current. For defect-free steel the back effect of the coil is constant. If a surface defect is present, this change in eddy current pattern can be picked up either by the original or by a separate coil. The current system uses six probes spinning at 2,000 rpm, giving a sweep every 5 mm. Figure 6 shows a schematic view.

### Running Surface Flatness Measurement

Rail surface waveforms introduced during manufacture have a significant effect on the stress pattern and hence life of rail and associated equipment, and in some instances on structure some distance away from the track. Although every effort is made to control these, the sources are many. Accurate measurement is therefore one way of obtaining feedback for greater control.

In May 1986 BSC introduced a laser system for measuring rail running surface flatness. The system uses six laser units, which are calibrated against a straightedge so that datum positions are established within the controlling computer software.

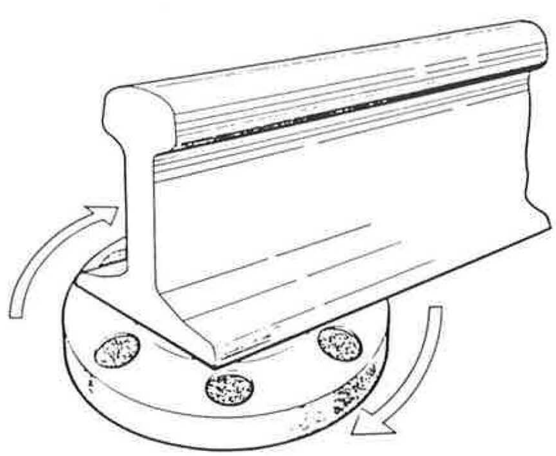

**FIGURE 6 Eddy current testing.**

At each measurement interval the two outer probes are used to establish the current position of the straightedge in space. The central four lasers measure the relative position of the rail surface, and this information is stored for subsequent wavelength and amplitude analysis. Characteristic wavelengths and maximum amplitudes are displayed in tabular and graphical form. Figure 7 shows the laser system and Figure 8, a typical waveform printout.

### Rail Straightness Measurement

Straightness measurement is a simplified form of surface flatness measurement but taken over a long wave. Three laser units in both the vertical and horizontal planes are used. The two outer lasers define the straightedge, and the central laser measures the deviation from straightness. The equipment is being installed at the exit from the straightener machine and should give almost instant feedback to the straightener's mathematical model. Unfortunately, straightness adjustment, although motor driven, will still be manual for some time to come.

As an aside on rail straightness, rails with a good crown profile for wheel guidance in track move through the roller straightening machines more readily and finish as straighter rails than do more poorly designed rails. The 132-lb American rail performs well in this respect.

### Rail Section Measurement

Lasers are being installed to measure principal dimensions and twist. It is not anticipated that this equipment will improve the rail, but it will give customers more peace of mind.

## RAIL WEAR PROPERTIES

Other things being equal, the best wear resistance is given by rails that have 100 percent fine pearlite structure and high hardness. Wider pearlite spacings or any alternative microstructure gives increased wear. Figure 9 shows true fine lamellar pearlite and Figure 10 shows degenerate pearlite, both originally photographed at ×6,250. Both structures look fully acceptable under a light microscope at ×500.

The one known exception to the pearlite rule is austenitic manganese rail, which gives very good service in certain types of wear situation only.

Figure 11 shows laboratory results that support site trials carried out by BSC.

Historically BSC has manufactured rails that range in hardness from 240 to 340 Brinnell Hardness Number (BHN) by a combination of controlled fan cooling during head transformation only in the mill and the addition of alloying elements such as chromium. Up to around 340 BHN the technique was successful, but above 330 BHN, there was a weld cost penalty. On increasing hardness over the range 340 to 400 BHN using alloy systems, it became extremely difficult to avoid the presence of degenerate forms of pearlite and even some traces of bainite. Consequently, although the hardness increased, the wear performance did not improve to the expected degree. For

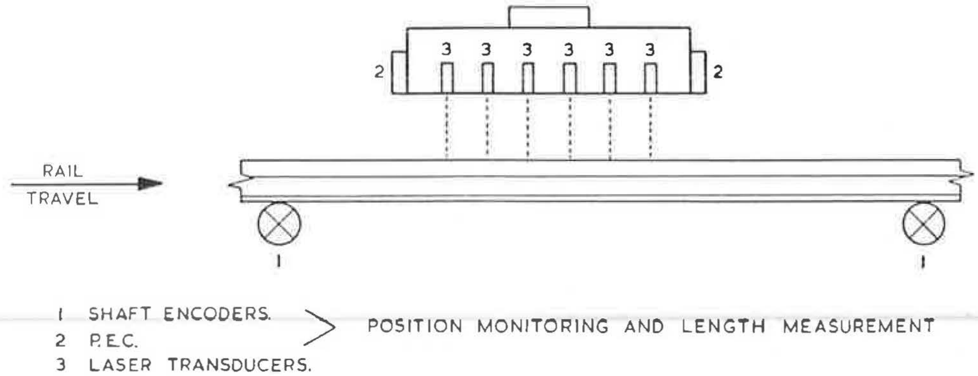


**FIGURE 7 Rail surface flatness measurement.**

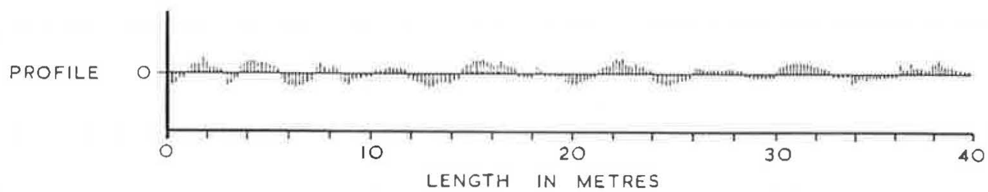


**FIGURE 8 Rail surface flatness profile.**

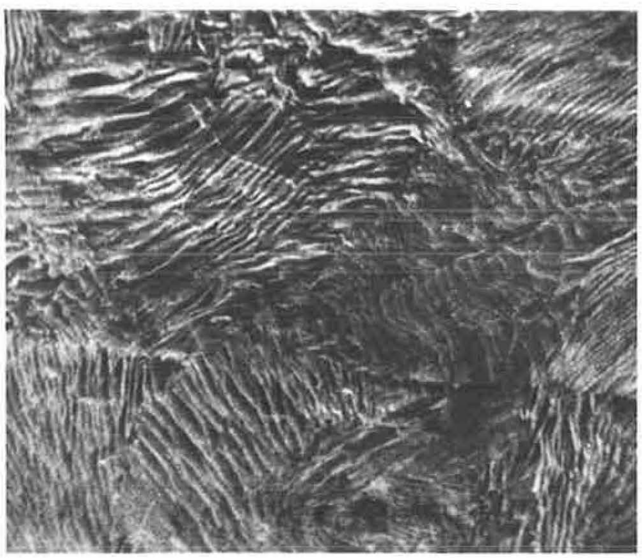

**FIGURE 9 Fine lamellar pearlite structure (×4,745).**

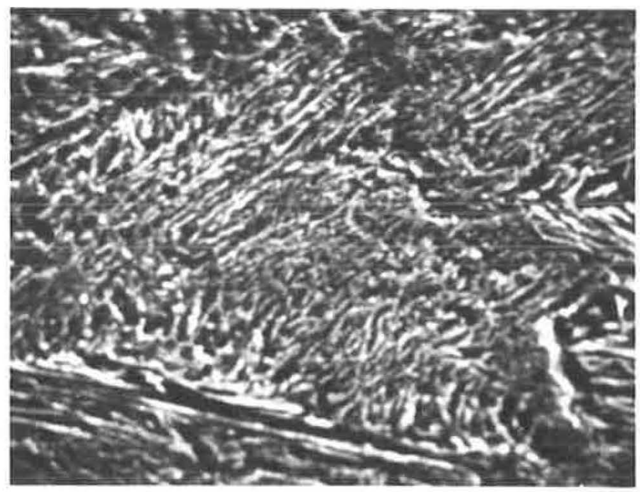

**FIGURE 10 Lamellar and degenerate pearlite (×4,550).**

these harder and more wear-resistant rails, BSC had the long-term aim of using on-line mill heat treatment, but in the short term turned to the more immediately available off-line head hardening type plant. The resulting pearlites follow (Figure 11), at least to the 425 BHN tested.

Off-line treatment was expensive, and even while the equipment was being installed, BSC was cooperating with the Centre de Recherches Métallurgiques (CRM) in Liège, Belgium, and Métallurgique et Minière de Rodange-Athus (MMRA) in the development of the new on-line process. The two processes are briefly described here.

## Off-Line Head Hardening

Rails are passed through a four-inductor heating unit that penetrates deep into the head of the rail. The rail surface reaches 1000° to 1050°C at around 20 mm/sec. After a free air soak period the rail is precooled with air to transformation temperature. The major part of the transformation then takes place in still air.

The hardness profile for a 132-lb carbon rail shows that, although produced off line, this is very much a deep-hardened rail. A relatively flat hardness profile is produced, so that the underlying rail is hard enough to support the wearing top surface. The base rail in this instance would have a hardness of 290 BHN. All manufacturing parameters are fixed at the start of a contract and are not altered for any reason. Computer control is therefore unnecessary. The machine performance is continuously recorded on a multipoint system, and the charts can be read once a day to confirm that all rails are treated within specifications. Obviously all normal mechanical and hardness tests are also carried out.

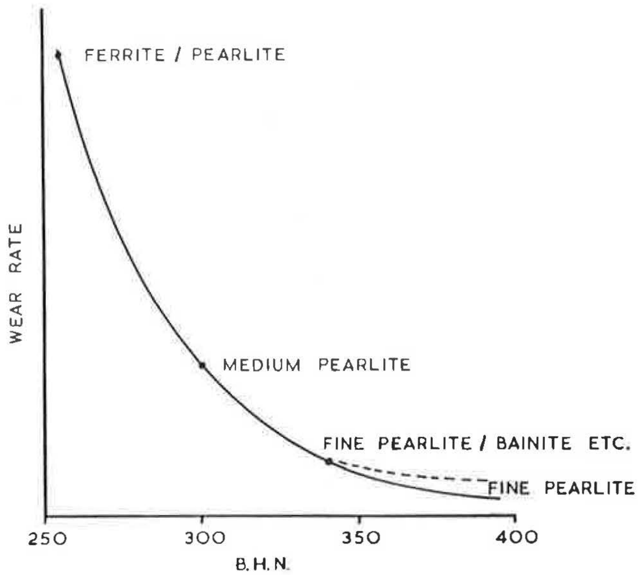


**FIGURE 11 Laboratory wear tests.**

## Mill Hardening

The idea for the plant was developed by CRM and the pilot plant was installed at MMRA. The full 130-tonne/hr production unit was installed by BSC and began operating in September 1987.

CRM had been heavily involved in on-line cooling of lower-carbon steels for over 20 years, and the development to higher-carbon and rail steels was a logical outcome of their work. Their first actual trial runs of on-line treated rails were carried out at MMRA in 1982. By 1984 the feasibility of the process had been fully demonstrated. The current pilot plant was completed in September 1985, and this equipment has successfully worked through a test program of over 14,000 tonnes of rail.

The general layout of the plant at MMRA is shown in Figure 12, and Figure 13 shows the process control system.

The plant at BSC is similar but with a size difference of ×2.5. The sequence of events is as follows: The hot rail passing from the finishing stands at 1000°C is placed head up. The rail then passes under temperature monitors that supply the temperature profile along the rail length to the computer. The rail passes through a cooling train (54 m long at BSC) in which rollers maintain both drive and straightness of the rail and water sprays all surfaces continuously as required over the length of the cooling train. The outgoing rail leaves the cooling area at a dull red heat, and the main transformation to pearlite structure takes place in still air. The straight rail is turned on its side and passes down the cooling banks for finishing in the normal manner.

Needless to say, the whole process is fully computer controlled. In fact, the plant at MMRA at 65 tonnes/hr and that at BSC at 130 tonnes/hr do not require any operators.

A wide range of sections, including asymmetric shapes, have been successfully produced at MMRA, and extensive testing has been carried out by BSC, MMRA, and CRM.

The process is very controllable and a hardness range of 300 to 400 BHN can be encompassed. Figure 14 shows a typical hardness pattern for a 132-lb rail.

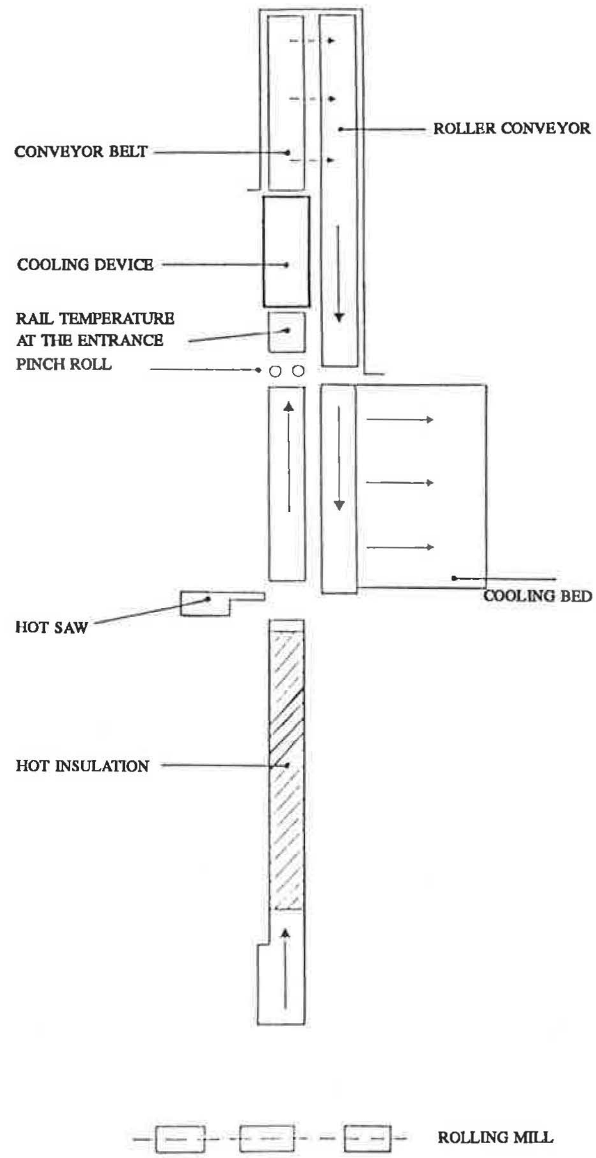


**FIGURE 12 Layout of heat treatment facilities.**

This rail also has the desirable flat hardness profile of great depth, and as with the BSC off-line treatment, the still-air transformation eliminates the possibility of a sharp hardness cut-off or transition zone.

Full mechanical testing and metallography have been carried out, and when conditions are met, wear results appear as those in Figure 11.

Full-section fatigue tests have also been carried out at BSC's Swinden Laboratories. Here results were found to be dependent on steelmaking and rolling techniques rather than treatment or strength. However, continuing work on push-pull fatigue testing in the transverse direction indicates that sulfur may have an effect on fatigue.

## SUMMARY

BSC rail development has been aimed at producing a basic rail that is clean and hydrogen and defect free to the extent that modern technology will allow. Such rail can be heat treated on

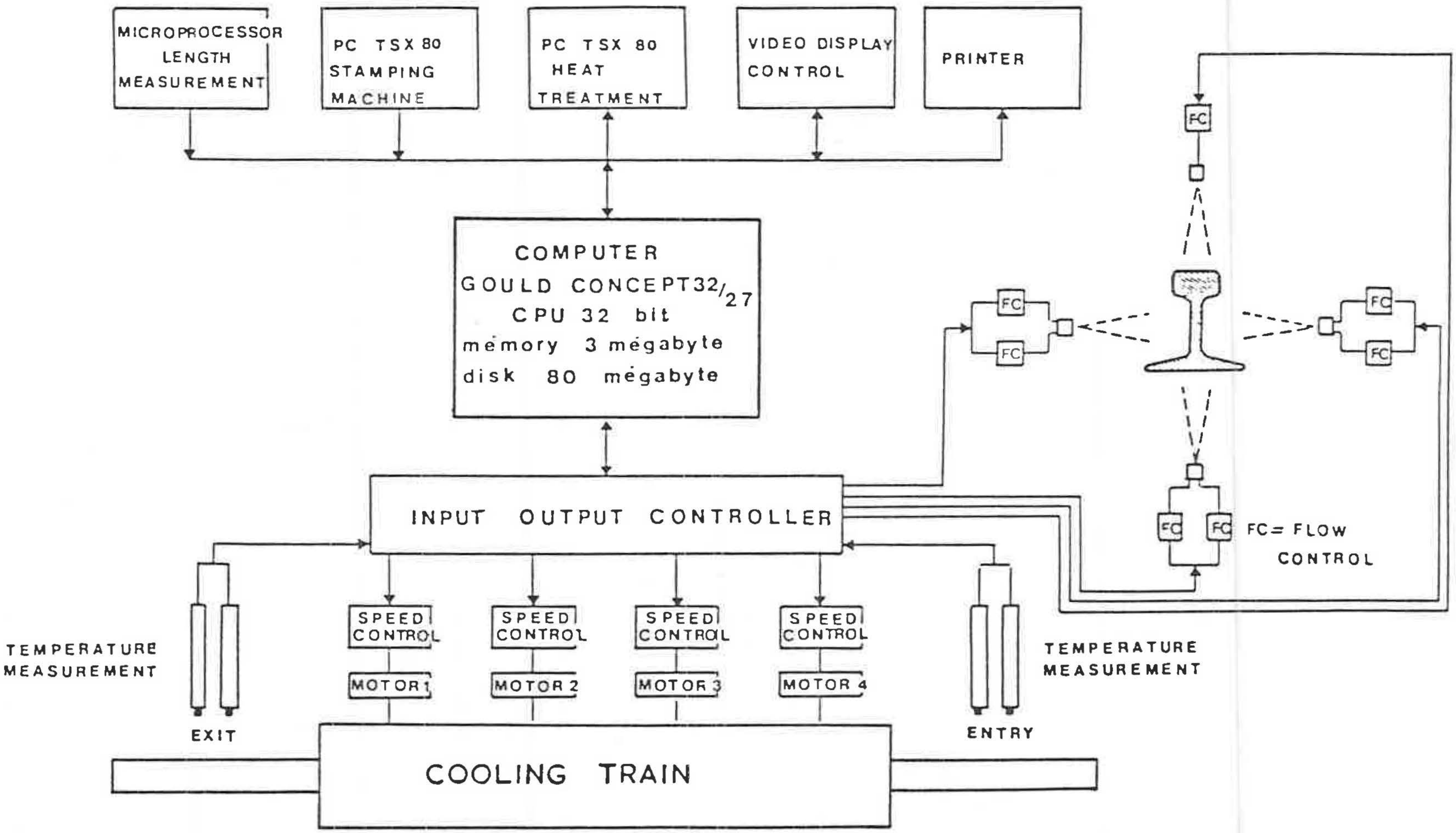


**FIGURE 13** Process control system for mill hardening.

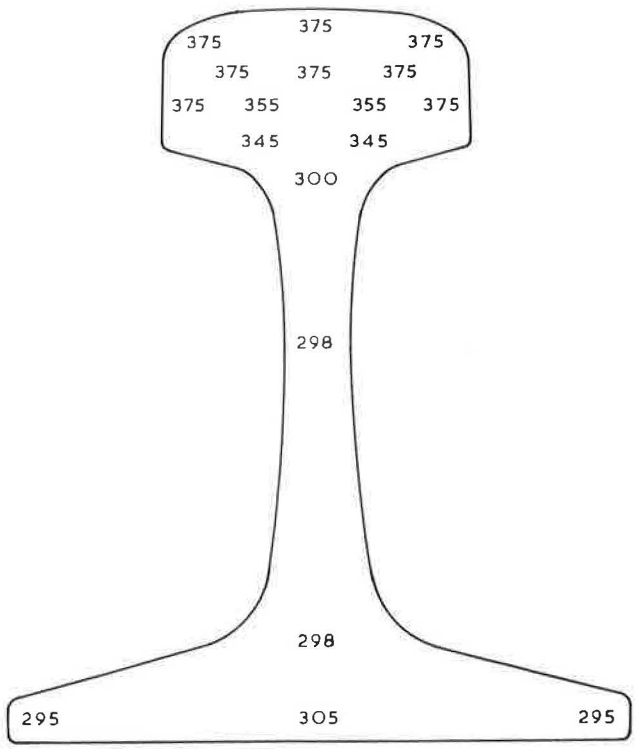


**FIGURE 14 Brinell hardness pattern for 132-lb rail.**

or off line to give hardness values in a continuous band from 300 to 400 BHN. This new technological package offers the railroads a complete break from the previous restrictive steps involved in the chemistry-controlled process. Rail can be produced anywhere in the 300- to 400-BHN band and can therefore give the user the benefit of the correct wear resistance for his particular system on tangent shallow curves, severe curves, and million-gross-tonne-per-year traffic, and satisfy his views on rail grinding. This can bring about a fine balance between surface fatigue and wear rate.

The majority of these improvements have come about without pro rata increases in cost relative to the improvements obtained, which is generally possible when the improvements are brought about by manufacturer push rather than market pull. The overall package should therefore be a very cost-effective offer to railroads and sets a pattern for the next decade.

## ACKNOWLEDGMENTS

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