

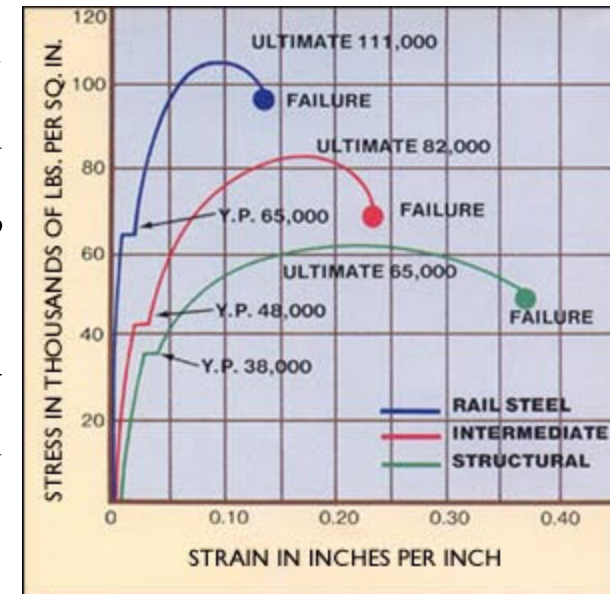
Modern railway systems are subjected to intense use, with fast trains and increasing axle loads. Rails have to be more wear resistant and achieve higher standards of straightness and flatness in order to avoid the surface and internal defects which may lead eventually to failure. The shape of the manufactured rail depends to a large extent on the uniformity of thermo mechanical processing; the most advanced mills are computer controlled with continuous feed-back from the product during manufacture.

Up until the 1970s, rails for passenger and freight trains were regarded as relatively simple undemanding products and the specifications had changed very little for decades. However, investments in railway systems, the advent of high-speed passenger trains and the requirement for longer life track imposed a demand for rails of high quality, greater strength and tighter geometric tolerances. Therefore there have been major innovations in the past 20 years in terms of the method of manufacture, degree of inspection and range of products.

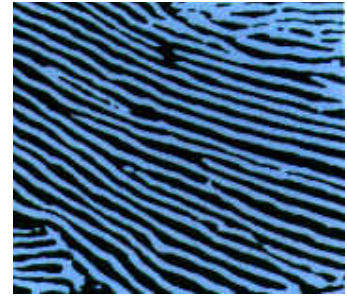
Rail steel is extremely tough. In addition, rail steel has satisfactory amount of ductility

Their average yield point is greater than 450 MPa, while actual tensile strength normally ranges from 700 to 900 MPa. This high yield point means rail steel provides ample stiffness, enduring heaviest demands with little deformation.

Even after years of service and high stress, there is no difference between the grain structure of a used rail and a new rail. Age, traffic and weather do not change its basic properties. All stresses are relieved through heating prior to being re-rolled. This re-rolling, in accordance with ASTM-A-499, decreases the rails' grain size, and that means improved resiliency. The additional working of the steel actually makes it better than when it was a rail!



The first steel rails used anywhere in the world were laid in Derby station on the Midland Railway in 1857. The metallurgical structure of those rails was essentially the same as that of the rail steel still used today - **a pearlitic structure based on a C-Mn composition.**



Rail and wheel wear from train operations is inevitable

In the past five years, railroads have purchased close to 500,000 tons of replacement rail per year at an estimated total cost of \$1.25 billion making even a small improvement in rail performance financially significant



The first British Standard for rail steel manufacture was BS11 issued in 1903 which required a minimum tensile strength of 618 N mm⁻².

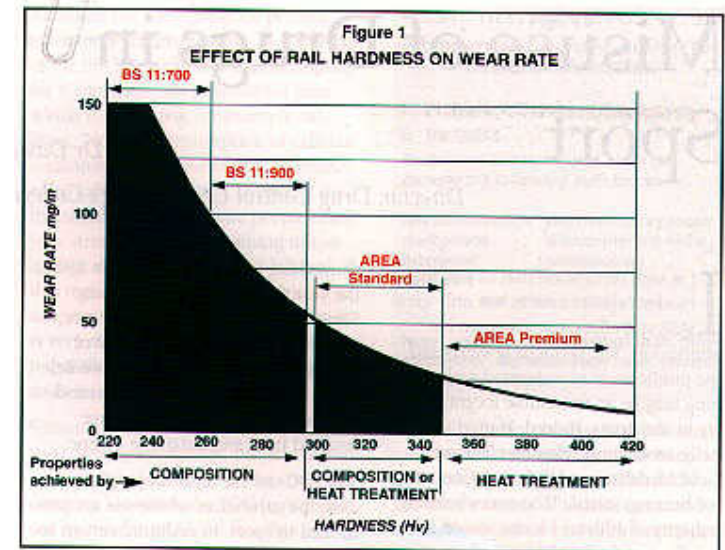
Since then, there have been twelve revisions leading to the current 1985 edition.

Strength requirements are now 710 N mm⁻² for the "Normal" grade and 880 N mm⁻² for the so called "Wear Resistant" grade.

The last 20 years have seen further increases in strength, mainly to cater for the heavy axle loads of North America and "**Premium**" rails of around 1300/1400 N mm⁻² tensile strength, are now used in large quantities.

These high strengths are achieved by making the spacing between the pearlite lamellae finer by controlling the growth rate of pearlite.

Alloying elements such as chromium and nickel can be added to some rail steels to improve properties.



Identification of the best steel properties will result in longer rail life.



The railroad industry continuously strives to safely reduce costs of railroad operations. Because rail is one of the industry's major capital costs, there is a drive to get more life out of the rail. And, since **wear and surface fatigue are main drivers of rail replacement**, the goal is to develop rail steel microstructures that give reduced wear and better fatigue resistance, hence, longer life for safe operation and reduced track maintenance costs.

Based on results from tests conducted at the Transportation Technology Center's Facility for Accelerated Service Testing, track costs of implementing 39-kip wheel load traffic were estimated at 20 to 50 percent more than with 33-kip wheel load traffic. (1kip=4.449 kN)

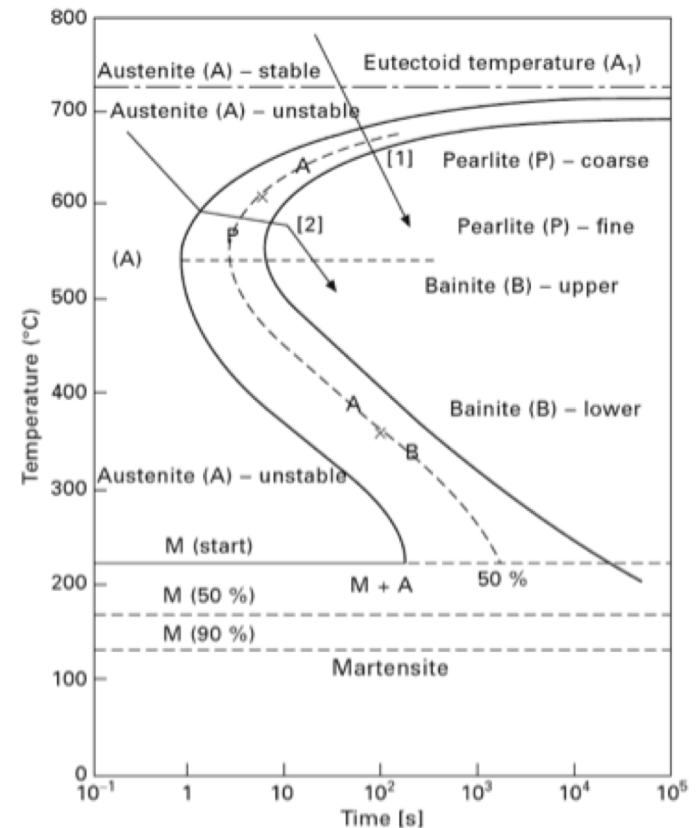
The ability of today's rail manufacturers to produce rail with a fully-pearlitic microstructure and hardness of 400 BH_n is an impressive achievement. ***An increase in tensile strength of about 200 MPa doubles the wear resistance of the rails and consequently their service life.***

With few exceptions, rail is made of carbon-manganese steel with pearlitic microstructures.

In pearlite, alternating layers of iron and iron carbide are arranged in colonies (groups), and the spacing between the layers has a large effect on hardness. **A finer spacing leads to higher hardness and better wear resistance.** With **natural cooling**, standard rail has a coarse spacing and relatively-low hardness, about 300 BH_n. With the **controlled cooling used in head hardening**, premium rail has finer spacing and thus higher hardness (340-400 BH_n) and better wear resistance.

North American railroads commonly use **standard rail in tangent track and in curved track up to about two to three degrees.** At higher curvatures, **premium rail is normally used.**

Wear consists of natural wear (from wheel/rail contact) and metal removed by grinding to remove rolling contact fatigue (rcf), surface defects and to re-profile the rail. **Modern steel manufacturing processes that produce cleaner and harder steel have improved wear and rcf performance and the incidence of defects from inclusions. However, even more improvements are sought by the railroads.**



Wear and rolling-contact fatigue

When wheels roll on rail, the forces produced lead to large shear stresses in a thin layer at the rail surface.

These stresses cause the steel to flow along the rail and the plastic deformations can lead to wear flakes. In some circumstances, these flakes can lead to deeper cracks through rolling-contact fatigue.

This process involves "ratcheting". The ratcheting process--rather like a leaning deck of cards.

So it seems that shear yield strength is likely the most important rail property for wear and rcf.

However, things are not so simple. This is because, in service, the surface of the rail is so heavily cold-worked that its properties bear little relation to the bulk rail properties. *What is important is the shear yield strength of the cold-worked and work-hardened surface, rather than the yield strength of the as-manufactured rail.*

**Bainitic rail steel with higher hardness than current premium rails
(420 BHN compared to 370 BHN pearlitic)**

Despite the higher hardness, the bainitic steel wore approximately 50 percent faster than premium rails in a minimally lubricated five-degree curve carrying heavy-axle-load cars.

This suggests that work-hardening does not increase the shear yield strength of bainitic microstructures as much as pearlitic microstructures.

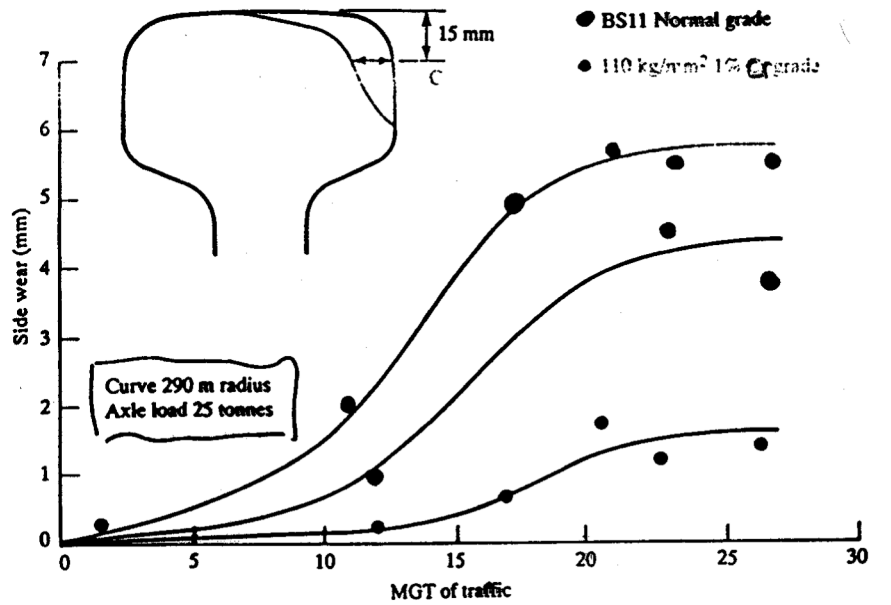
Thus, microstructure plays a significant role in wear and rcf

But how and why? And more importantly, what properties or characteristics of a metal influence and/or control shear yield strength?

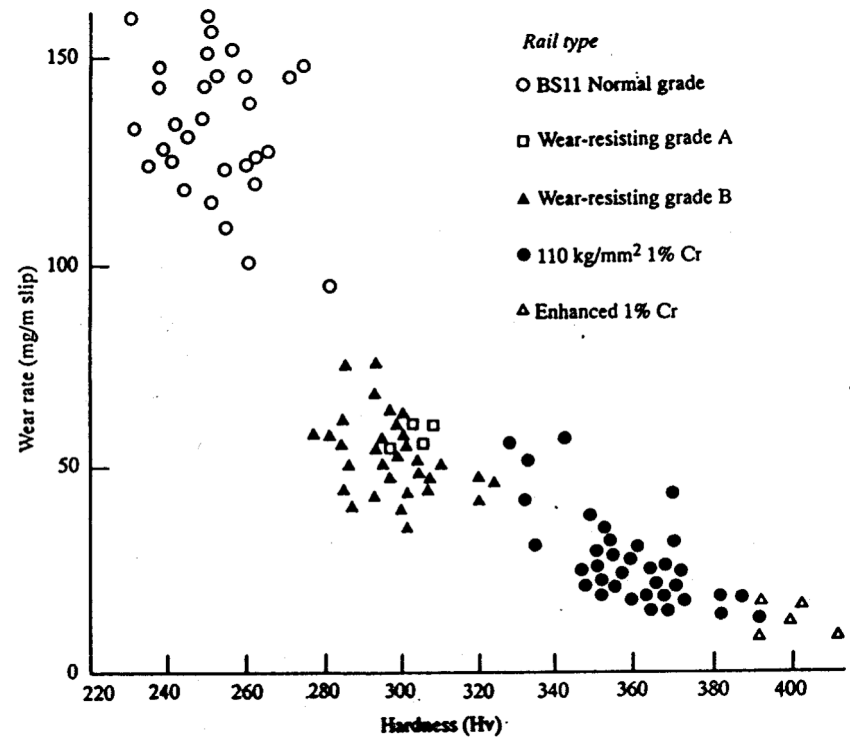
Properties and contact stresses

The shear yield strength of interest is that developed in the work-hardened surface layer at the strain rates applied by the wheel, and is dependent on the following:

- As-manufactured (bulk) **shear yield strength**.
- **Work hardening of the rail surface**. The surface layer can be twice as hard as the bulk.
- **Strain rate**. High strain rates raise yield strength. This may be a significant effect at the very-high strain rates in wheel/rail contact.



Side wear in normal and 1% Cr rails under identical service conditions



Effect of hardness on wear rate in laboratory tests

Manganese in steel

The abundance of manganese in the iron ore used by the Spartans helped to produce a sword tougher than those of their military opponents.

Most steels contain 0.15 to 0.8% manganese.

High strength alloys often contain 1 to 1.8% manganese.

At about 1.5% manganese content, the steel becomes brittle, and this trait increases until about 4 to 5% manganese content is reached. At this point, the steel will pulverize at the strike of a hammer.

Further increase in the manganese content will increase both hardness and ductility. At around 10% manganese content the steel will remain in its austenite form at room temperature. Both hardness and ductility reach their highest points around 12%, depending on other alloying agents.

Non-magnetic with 11% - 14% manganese.

Manganese steel has excellent work hardening properties. Suitable for wear applications where high impact/gouging abrasion leads to a work hardening effect.

In 1882 Robert Hadfield discovered Manganese steel which was hardened by quenching it in water

The hard steel was to be used in the manufacture of tram wheels.

Due to the considerable costs involved in the production of Mn steel it was not until 1892 that any other firm became involved in it's production.



The first World War provided new markets for manganese steel, spur armour plate and shells, tank treads and soldier's helmets.

By 1919 Hadfields were Sheffield's biggest employers, 15000 and was probably the largest special alloy steel manufacturer in the country. A new market had opened up for silicon steel in the manufacturer of electrical transformers.



Hadfield steel - 12% Mn

It is a long-standing tradition to discuss the various alloying elements in terms of the properties they confer on steel.

For example, the rule was that Chromium (Cr) makes steel hard whereas Nickel (Ni) and Manganese (Mn) make it tough.

This method of reasoning can give false impressions and the following examples will illustrate this point.

When we say that **Cr** makes steel hard and wear-resisting we probably associate this with the **2% C, 12% Cr tool steel grade**, which on hardening does in fact become very hard and hard-wearing.

But if, on the other hand, we choose a steel **0,10% C and 12% Cr**, the hardness obtained on hardening is very modest.

Most steels contain 0.15 to 0.8% Mn. High strength alloys often contain 1 to 1.8% Mn. At about 1.5% Mn content, the steel becomes brittle, and this trait increases until about 4 to 5% Mn content is reached. ***At this point, the steel will pulverize at the strike of a hammer.*** Further increase in the manganese content will increase both hardness and ductility. At around 10% Mn content the steel will remain in its austenite form at room temperature if cooled correctly. ***Both hardness and ductility reach their highest points around 12%, depending on other alloying agents.***

The material is very resistant to abrasion and will achieve up to three times its surface hardness during conditions of impact, without any increase in brittleness which is usually associated with hardness. This allows **mangalloy** to retain its toughness..

Sufficiently large amounts of **Ni** or **Mn** render a steel austenitic even at room temperature.

An example of this is the so-called Hadfield steel which contains

13% **Mn** 1,2% **Cr** 1% **C**.

In this steel both the **Mn** and **C** take part in stabilizing the austenite.

The original austenitic manganese steel, containing about 1.2% C and 12% Mn, was invented by Sir Robert Hadfield in 1882. Hadfield's steel was unique in that *it combined high toughness and ductility with high work-hardening capacity and, usually, good resistance to wear.*

Many of mangalloy's uses are often limited by its difficulty in machining. The metal cannot be softened by annealing, and usually requires special tooling to machine. The material can be drilled with extreme difficulty using diamond or carbide. Although it can be forged from a yellow heat, it may crumble if hammered when white-hot, and is much tougher than carbon steel when heated. It can be cut with an oxy-acetylene torch, but plasma or laser cutting is the preferred method.

Hadfield has a yield strength between 345 MPa to 414 MPa.

Although stronger than low carbon steel, it is not as strong as medium carbon steel. It is however, much tougher than medium carbon steel. Yielding in this steel signifies the onset of work hardening and accompanying plastic deformation.

The ability to work harden up to its ultimate tensile strength is its main feature. In this regard it has no equal. The range of work hardening from yield to ultimate tensile is approximately 200%.

WHY IS DIFFERENT FROM CASE-HARDENED STEELS?

With case-hardened steel, the depth of hardness is fixed. When Hadfield is subjected to wear the hard surface continuously renews itself.

Depending on deformation of the surface crystalline structure, it can work-harden up to more than 500 Brinell. When originally put into service it is about 200 Brinell.

Hadfield's steel is used extensively, primarily in the fields of earthmoving, mining, quarrying, oil well drilling, steelmaking, railroading, dredging, lumbering, and in the manufacture of cement and clay products.

Austenitic manganese steel is used in equipment for handling and processing earthen materials (such as rock crushers, grinding mills, dredge buckets, power shovel buckets and teeth, and pumps for handling gravel and rocks). Other applications include fragmentizer hammers and grates for automobile recycling and military applications such as tank track pads.

Carbon content above 1.4% is seldom used because of the difficulty of obtaining an austenitic structure sufficiently free of grain, boundary carbides, which are detrimental to strength and ductility.

HOW DOES IT WORK IN VERY LIGHT ABRASION?

Not so well. It may outwear mild steel a bit but usually there is not enough surface deformation to work-harden

WHAT ABOUT CORROSION RESISTANCE?

No better than ordinary steels. It rusts and is attacked by acids to about the same extent.