NIOBIUM IN RAIL STEELS

J. G. Williams, I. D. Simpson and J. K. MacDonald

Australian Iron and Steel Pty. Ltd.
Post Office Wollongong NSW
Australia

Introduction

Recent developments in the highly competitive transportation industry have led to ever increasing demands being placed on railroad systems. While conventional carbon steel rails have provided faithful service in a wide range of service environments for many years, there are some applications where they have been found wanting and the use of higher strength steels of improved quality has been necessary to ensure satisfactory and safe service. These applications include high speed tracks in the mining industry and heavy duty load bearing units in steelplants, both of which have been required to accommodate substantial growth in steelmaking capacity and output. The cost of replacement of worn or defective rails in such cases can be excessive. When evaluated in respect of losses in production and of the inconvenience of effecting repairs in remote locations with difficult terrains and adverse conditions, this is especially true. Such locations are frequently encountered in the winning of iron ore from vast deposits in South Africa, Western Australia, Brazil and Sweden.

The development of methods for imp'roving the service life of railway materials has been the subject of extensive research over the past decade and data presented at international conferences (1, 2, 3, 4) have highlighted many of the problems involved. These data have clearly demonstrated that rails should have reasonable weldability, a high resistance to wear and/or deformation and should also possess other important characteristics such as are necessary to ensure adequate safety against failure by fatigue or fracture under the intended operating conditions.

In order to satisfy these requirements, close attention has to be paid to steelmaking procedures with the aim of producing clean steel free from hydrogen-induced defects. Special deoxidizing and casting conditions are adopted to ensure minimum non-metallic inlcusion content, and low-hydrogen melting or vacuum-degassing can be adopted as alternatives to controlled-cooling of finished rails to achieve low hydrogen contents (5). Ultrasonic testing is applied to confirm that the rails satisfy specific standards for internal soundness.

Increased service performance can also result from the use of high strength rails. For example, it has been shown (6) that in the case of 100 tonne cars operating on a 2° curve, rail life for high strength steel can be greater than that for conventional carbon steel by a factor of 1.6 to 3.0.

The properties of particular importance to rail life are tensile strength and hardness, higher levels of which promote increased resistance to wear and deformation, and improved fatigue strength (5). Resistance to deformation is mainly dependent on yield strength which is related to tensile strength. While wear resistance is improved as hardness increases, steels with different microstructures but the same hardness do not exhibit the same wear resistance (7). In this respect, pearlite is superior to tempered martensite which, in turn, is superior to bainite.

The properties of pearlitic rail steels are influenced by the spacing between cementite lamellae, their thickness and the pearlite colony size (8). Yield and tensile strength increase as the interlamellar spacings decrease while toughness is governed by the thickness of the lamellae and pearlite colony size. Fine pearlitic structures may be achieved either by heat-treatment or by alloying.

Manganese and chromium are effective in producing fine pearlitic structures through lowering of the transformation temperature and indications of their respective contributions to strength are given by the regression equations of Heller and Schweitzer (9). Further strengthening can be achieved through precipitation hardening by virtue of the formation of finely dispersed precipitates in ferrite lamellae of the pearlite, such as may result from the microalloying addition of niobium.

Niobium in High Carbon Steel

The microalloying addition of niobium to high carbon steel can, under appropriate processing conditions, result in increased strength and improved ductility. The extent to which such property improvement may be achieved is largely controlled by the amount of niobium in solution in austenite prior to rolling. Solution of niobium carbonitride precipitates is particularly sensitive to soaking temperature and carbon content as indicated in Figure 1 (10). Depending on soaking conditions and compositional factors, some niobium carbonitrides may remain undissolved in austenite and consequently have little effect on the steel properties. On the other hand, niobium taken into solution during soaking can, during,subsequent rolling, retard austenite recrystallization through solute drag effects and strain induced precipitation of niobium carbonitride in austenite (11), ultimately resulting in refinement of the pearlite colony size. Any niobium remaining in solution in austenite at the finish rolling temperature may be available for subsequent strengthening by precipitation in pro-eutectoid ferrite and in the ferrite lamellae in pearlite after transformation.

Experience with Rail Steels Containing Niobium

The influence of microalloying niobium additions on the properties of rail steels was originally investigated in a co-operative program that was undertaken in the U.S.A. by Molycorp and The Colorado Fuel and Iron Company (12). Niobium additions were made to ingots of a heat of basic analysis 0.74 percent C, 0.80 percent Mn and 0.14 percent Si to obtain niobium contents of

0.015 percent - 0.047 percent. Improvements in yield and tensile strength of up to 11.4 percent and 4.4 percent respectively were achieved along with slight improvements in ductility (Table I), but subsequent in-track tests showed performance not greatly different from that of carbon steel rails (13).

At Domnarvets Jernverk, Sweden, the effect of niobium on the properties of UIC rail steels was studied (14). It was found that niobium increased the tensile strength by 98 MPa (14.2 k.s.i.) and improved the wear resistance of the rails.

Silicon-manganese-niobium rail steels have been produced by the Brazilian National Steel Co. (CSN) since 1972. Their Niobras-200 steel is typified by the chemical composition and mechanical properties shown in Table I. The improved properties as compared to those of conventional carbon steel rails were ascribed to the influence of niobium as a grain refiner and the subsequent finer pearlite colony size. Weldability of the steel was reported to be good both in flash-butt and thermite welding processes (12). The details of this steel are presented in a separate paper at this Conference (15).

Some 1000 tonnes of chromium-niobium steel rails were produced for trial purposes by ISCOR, South Africa. The objective of the niobium addition was mainly to improve the toughness of the rails (16). Yield and tensile strengths of as high as 735 MPa (106.7 k.s.i.) and 1215 MPa (176.3 k.s.i.) respectively were achieved in combination with elongations of around 14 percent. The average composition and mechanical properties representing 28 heats of this steel are shown in Table I.

As a result of their development program on alloy steel rails, Thyssen AG, West Germany, reported that niobium was considered to retard transformation to pearlite and to adversely affect weldability (17). Specific details of the base composition were not mentioned.

In laboratory work at Climax Molybdenum Co. (18), the influence of niobium additions to base compositions of 0.66-0.68 percent C, 0.61-0.88 percent Mn, 0.51-0.82 percent Cr, and 0.24-0.30 percent Mo was examined. It was demonstrated that, at the lower molybdenum content, the effect of 0.02 percent niobium was to substantially improve ductility as defined by reduction-of-area in the tensile test, but in this respect no improvement occurred with the 0.30 percent molybdenum steel. In the latter case, the mechanical properties were largely influenced by the proportion of bainite in the microstructure, this being increased by faster cooling rates and higher niobium contents leading to predominantly bainitic structures and relatively low strengths.

Investigations in Belgium (19) resulted in the development of a relatively low carbon Cu-Ni-Cr-Nb steel mainly for application in crane rails. The data from laboratory research programs indicated that yield strengths of 590-785 MPa (85.6-113.8 k.s.i.) could be achieved with compositions within the range 0.10-0.30 percent C, 1.7-1.9 percent Mn, 0.4-0.6 percent Si, 0.4-0.6 percent Cr, 1.1-1.3 percent Cu, 0.8-1.0 percent Ni, 0.04-0.06 percent Nb and 0.04-0.10 percent Al. Heavy section 101 kg/m (205 lb/yd) crane rails with 0.22 percent carbon, and with other elements within the proposed range, exhibited yield and tensile strengths of at least 685 MPa (99.5 k.s.i.) and 1080 MPa (156.6 k.s.i.) with elongation and reduction of-area values of up to 12 percent and 30 percent respectively. These properties were generally improved by ageing at 500 C (932°F).

Table I. Details of various high strength rails containing niobium.

Manufacturer	Chemical Composition (wt %)					Mechanical Properties							
						YS		TS		YS/TS	Elongn.	R.A.	Hardness
	C	Mn	Si	Cr	Nb	MPa	ksi	MPa	ksi		%	%	BHN
C.F. & I.	0.74	0.80	0.14	-	0.015	500	72.5	915	132.7	0.55	10.0	19.2	267
					0.030	525	76.1	925	134.2	0.57	8.8	19.7	267
					0.047	535	77.6	940	136.4	0.57	9.3	20.1	269
Brazilian Steel Co.	0.78	1.33	0.79	-	0.028	625	90.7	1115	161.7	0.56	9.8	18.9	327
Sydney Steel	0.70	1.10	0.75	0.80	0.060	705	102.3	1040	150.8	0.68	10.0	16.0	340
ISCOR	0.69	1.03	0.50	0.70	0.050	660	95.8	1130	163.9	0.58	11.5	25.0	-

At Australian Iron and Steel Pty. Ltd. (AIS) investigation of the effects of niobium on rail steels was undertaken in the early 1970's. The initial trials were concerned with the development of rails that would provide improved performance in crane tracks and other heavily loaded units at the steelplant (20, 21). In these applications, the principal mode of failure is associated with excessive deformation or "mushrooming" of the rail head and thus the main object of the trials was to develop rails of significantly higher yield strength than for conventional carbon steel rails, without adversely affecting other important properties such as ductility and weldability. Niobium additions of 0.025–0.045 percent to base steel containing 0.43 percent C, 1.52 percent Mn, 0.17 percent Si and 0.29 percent Cr gave improvements in yield and tensile strengths for 53 kg/m (107 lb/yd) rails of up to 39 percent and 7 percent respectively along with significantly better elongation and reduction-of-area values. To provide data with respect to service performance the niobium steel rails were installed in a section of the steelplant track that was used to convey rakes of ingots, moulds and stools and which was subject to an average wheel load of at least 24 tons on smaller diameter wheels than used for normal rolling stock. The niobium steel rails showed marked reduction in head deformation and their lives were at least twice those of conventional carbon steel rails.

Because of the promising results that were obtained in these trials the niobium containing rails were eventually produced in a range of rail sections as required for heavy duty service in the steelplant and in other industries. Typical compositions and properties are listed in Table II. The following cases indicate the extent of improvements that have been made possible with C-Mn-Cr-Nb pearlitic rail steels:

a. Standard carbon 47 kg/m (96 lb/yd rails were found to fail prematurely due to excessive head spreading and splitting in 6–12 months in a narrow gauge track at the BHP Co. Newcastle steelplant. The carbon steel rails were replaced with niobium containing rails of typical chemistry and properties as shown in Table II. After 4 years service the niobium steel rails had to be removed from the track because of ballast failure, and they showed limited wear and deformation of the heads, and freedom from internal defects. In this application the niobium steel rails thus exhibited lives of at least four times those of conventional carbon steel rails.

b. Heavy section 192 kg/m (390 lb/yd) rails are used in a slag-car transfer track at the Basic Oxygen Steelmaking Plant at Port Kembla. Carbon steel rails were originally used with average lives of 3 months before replacement was necessary as a result of excessive deformation and subsequent splitting of the uppermost part of the cross-section. Replacement of the carbon steel rails with C-Mn-Cr-Nb steel rails resulted in a six-fold improvement in life. The analysis and average properties of the 192 kg/m (390 lb/yd) rails are listed in Table II.

c. At Mt. Newman Mining Co. Pty. Ltd., accelerated wear was experienced with 68 kg/m (138 lb/yd) standard carbon rails which were subjected to mean axle loads of 30 tonnes force with peak loads up to 40 tonnes force. For instance, the high rails in a 2" curve were found to exhibit 25 percent head loss after 130 mgt. An in-track evaluation of alloy rail steels in a 2° curve demonstrated that the performance of C-Mn-Cr-Nb steels was equivalent to or superior to other alloy rails investigated with a 75 percent increase in rail life over standard carbon rails (22).

Table II. Details of high strength niobium containing rails produced by **AIS** PTY Ltd.

Railweight kg/m	(lb/yd)	Application*	Chemical Composition (wt %) Ave C	Mn	Si	Cr	Nb	Others	Mechanical Properties YS (0.2% PS) MPa	ksi	TS MPa	ksi	YS/TS	e. Elong. %	%	BHN	** Symbol
47	(96)	SR	0.65	1.33	0.13	0.65	0.054		678	(98.3)	1106	(160.4)	0.61	16	32	322	x
"	"	"	0.72	1.34	0.16	0.60	0.043		697	(100.1)	1156	(167.7)	0.60	14	25	334	+
53	(108)	"	0.43	1.52	0.17	0.29	0.045		601	(87.3)	940	(136.3)	0.64	12	37	288	a
"	"	"	0.50	1.29	0.21	0.75	0.028	0.025 Ti	660	(95.7)	1005	(145.8)	0.66	13	32	302	■
"	"	"	"	"	"	"	"	1.015 Ti	650	(94.3)	1003	(145.4)	0.65	13	34	300	□
"		"	"	"	"	"	"	0.003 Ti	674	(97.9)	1030	(149.4)	0.65	13	31	311	■
"	"	"	0.70	1.11	0.25	0.75	0.026		692	(100.5)	1124	(163.0)	0.62	11	26	325	0
"	"	"	0.64	1.12	0.25	0.80	0.028		682	(99.1)	1092	(158.4)	0.63	10	24	312	●
"	"	"	0.69	1.15	0.28	0.77	0.031		712	(103.4)	1143	(165.8)	0.62	10	21	329	◐
"	"	"	0.74	1.16	0.34	0.89	0.029		718	(104.3)	1189	(172.6)	0.63	10	24	344	◐
"	"	"	0.69	1.15	0.28	0.77	0.035		679	(98.5)	1119	(162.3)	0.61	12	33	322	△
"	"	"	0.64	1.20	0.26	0.74	0.030		705	(102.3)	1139	(165.2)	0.62	11	21	330	▲
60	(122)	"	0.73	1.28	0.31	0.99	0.030		671	(97.3)	1154	(167.4)	0.58	10	16	324	0
68	(138)	MR	0.65	1.71	0.32	0.87	0.069		719	(104.3)	1185	(172.0)	0.61	15	39	350	A
	"	"	0.82	1.11	0.52	0.87	0.043		701	(101.8)	1195	(173.5)	0.59	11	14	342	A
73	(148)	MS	0.65	1.22	0.13	0.68	0.055		683	(99.2)	1120	(162.4)	0.61	16	32	320	□
"	"	"	0.73	1.26	0.18	0.90	0.022		675	(38.0)	1164	(169.0)	0.58	10	20	331	■
"	"	"	0.70	1.18	0.16	0.77	0.036		694	(100.7)	1168	(169.6)	0.59	10	24	323	□
"	"	"	0.69	1.35	0.17	0.69	0.054		686	(99.6)	1164	(169.0)	0.59	11	24	318	☒
"	"	"	0.71	1.30	0.20	0.90	0.018		671	(97.3)	1145	(166.2)	0.59	11	22	322	□
86	(174)	SC	0.65	1.25	0.11	0.90	0.023		700	(101.5)	1130	(163.9)	0.62	10	13	321	
192	(390)	ST	0.70	1.20	0.18	0.85	0.020		601	(87.3)	1082	(156.9)	0.56	9	13	318	
"	"	"	0.69	1.09	0.24	0.75	0.054	0.060 Al	695	(100.8)	1140	(165.3)	0.61	12	15	321	

*SR = Steelplant rail tracks
MR = **Mining** industry rail tracks
MS = **Mining** industry stacker reclaimers
ST = Steelplant transfer tracks

** Refer **Figs** 2–7

Processing Aspects of C-Mn-Cr-Nb Rail Steels

Experience gained at AIS with the production of C-Mn-Cr-Nb high strength ingot cast rail steels has highlighted a number of compositional and processing aspects which are of importance in achieving the required strength and ductility. Some of these aspects are discussed below:

Effect of carbon content

At conventional ingot soaking temperatures of about 1260-1300 C (2300-2370°F) increasing the carbon content in the range of about 0.40 to 0.80 C can effectively reduce the amount of niobium in solution from about 0.035 to 0.015 (Figure 1). Clearly, under these circumstances, the effect of niobium on final properties will vary significantly. Work on C-Mn-Cr-Nb rails at AIS has suggested that with increasing carbon content in the range of about 0.40 to 0.80 the strengthening effect of niobium is gradually diminished such that at carbon contents above about 0.80 percent C little strengthening is achieved from niobium. However, ductility as measured by total elongation is apparently improved irrespective of the carbon content. These aspects will be described in more detail below.

Effect of finish rolling temperatures (FRT)

The finish rolling temperature (FRT) of rail steels at AIS is generally in excess of 950 C (1740°F). However, lower FRT may be obtained in the event of low reheat temperatures or inadequate soaking, unavoidable delays during rolling and/or low section weights.

In niobium steels, FRT can be an important factor in determining strength/ductility properties. At a given level of soluble niobium, the FRT essentially controls the extent to which strain induced precipitation in austenite and subsequent precipitation strengthening in the ferrite take place. High FRT promotes retention of niobium in solution in austenite thereby raising the capacity for precipitation strengthening of ferrite. On the other hand, a low FRT enhances strain induced precipitation of niobium carbonitride in austenite, which causes a reduced strengthening effect, but refines the pearlite colony size.

Work on C-Cr-Mn-Nb rails at AIS has indicated that a FRT in the range 1000-850 C (1830-1560°F) can have an important effect on strength at reduced carbon contents (i.e. at higher levels of soluble niobium). In Figure 2 it is clear that at relatively low carbon contents of 0.55 percent, both yield and tensile strength decrease steadily with decreasing FRT below about 1000 C (1830°F). This would be consistent with an increase in strain induced precipitation of niobium carbonitride in austenite with decreasing FRT at the expense of precipitation strengthening in the ferrite. The effect of FRT on the strength of 0.70 percent C steel is less pronounced probably on account of the lower level of niobium in solution and the likelihood that little remaining niobium would be available for precipitation hardening in the ferrite.

Hot torsion testing of C-Mn-Cr-Nb rail steel at BHP Melbourne Research Laboratories (23) has revealed that recrystallization of austenite at 1050 C (1920°F) is not much affected by the niobium addition. However, at 1000 C (1830°F) recrystallization becomes sluggish and, during normal rolling,

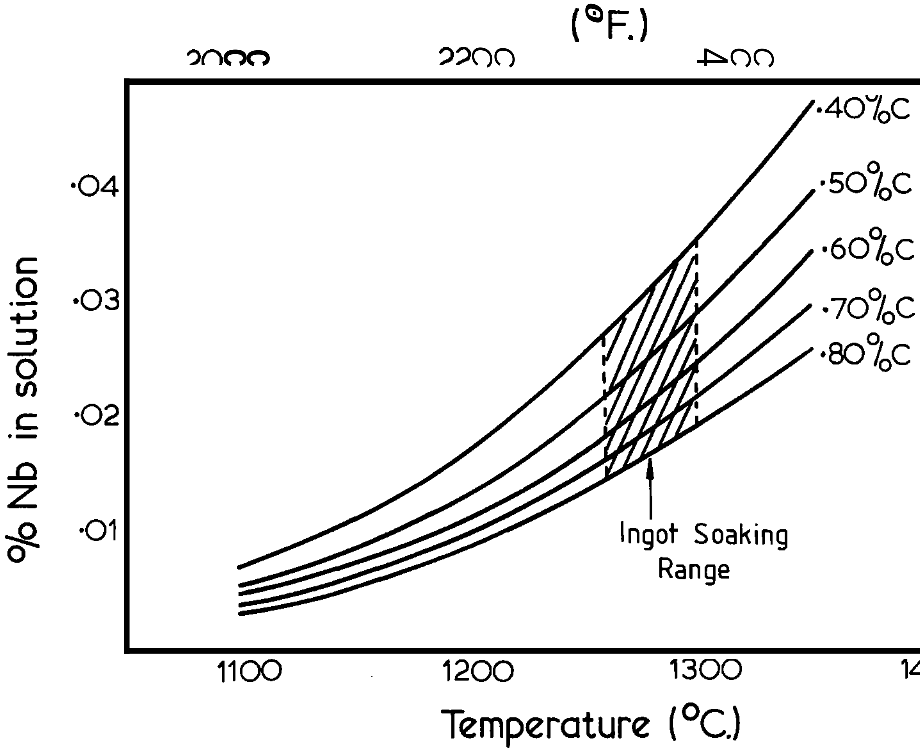


Figure 1. Nb(C,N) Solubility Curves in Austenite (10).

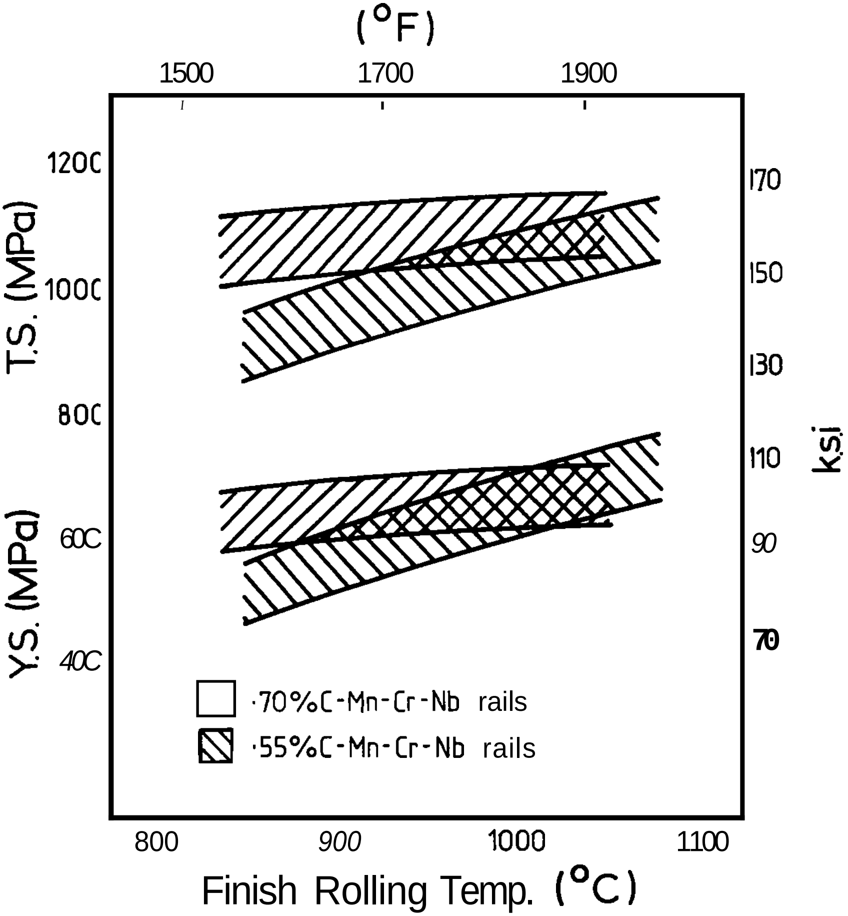


Figure 2. Effect of Finish Rolling Temperature and Carbon Content on Strength of C-Mn-Cr-Nb Rails.

niobium may severely retard recrystallization of austenite below about 950 C (1740°F). These effects of niobium on hot strength may be attributed mainly to the occurrence of strain induced precipitation of niobium carbonitride during rolling.

At FRTs less than about 950-1000 C (1740-1830°F) recrystallization may not be completed between passes. Under these circumstances recrystallization may occur differentially along the length of the rail or through the section of the rail and will be greatly influenced by temperature pradients and varying degrees of deformation. Experience gained at AIS has indicated that recrystallization occurring differentially in hot rolled rails may be responsible for shape and gauge problems. This is most pronounced in rails of reduced carbon content (i.e. high soluble niobium contents) and low FRT. In order to minimize these problems, finish rolling should be carried out at temperatures in excess of 1000 C (1830°F).

Properties of C-Mn-Cr-Nb Rail Steels

Strength and Ductility

As outlined above, the effects of niobium on the strength and ductility of rail steels are mainly governed by:

a. Soaking conditions and carbon content, which control the amount of niobium in solution, and

b. Finish rolling temperature, which controls the balance between strain induced precipitation in austenite and the level of subsequent precipitation hardening in the ferrite.

A comparison of the strength levels achievable with standard carbon, C-Mn-Cr and C-Mn-Cr-Nb rails produced at AIS is shown in Figure 3 for section weights in the range 47-73 kg/m (96-148 lb/yd). The yield strength advantage of C-Mn-Cr-Nb rails over standard carbon rails is generally maintained at a fairly constant level i.e. about 200 MPa (29 k.s.i.) over the entire range of C + Mn/4. The difference in tensile strength of niobium steels compared to plain carbon steels increases from about 150-200 MPa (22-29 k.s.i.) over the same range. At low values of C + Mn/4, the tensile strength increment in niobium steels is probably reduced as a result of the governing effect of carbon content on tensile strength.

In the range of C + Mn/4 where a comparison can be made with C-Mn-Cr rails, niobium steels still show an advantage of about 70-100 MPa (10-15 k.s.i.) for both yield and tensile strength. It is noticeable that the difference is diminished at high values of C + Mn/4, no doubt reflectinp the effect of carbon content which can control the strengthening potential of niobium.

The effect of carbon on the strengthening capacity of niobium may be more clearly demonstrated by making use of the predictive equations of Heller and Schweitzer for the strength of C-Mn-Cr steels (9). In Figure 4 (a), (b), actual versus predicted values for yield and tensile strengths are presented for niobium bearing C-Mn-Cr rails as well as some conventional C-Mn-Cr rails produced at AIS. Reference to the results obtained for conventional C-Mn-Cr

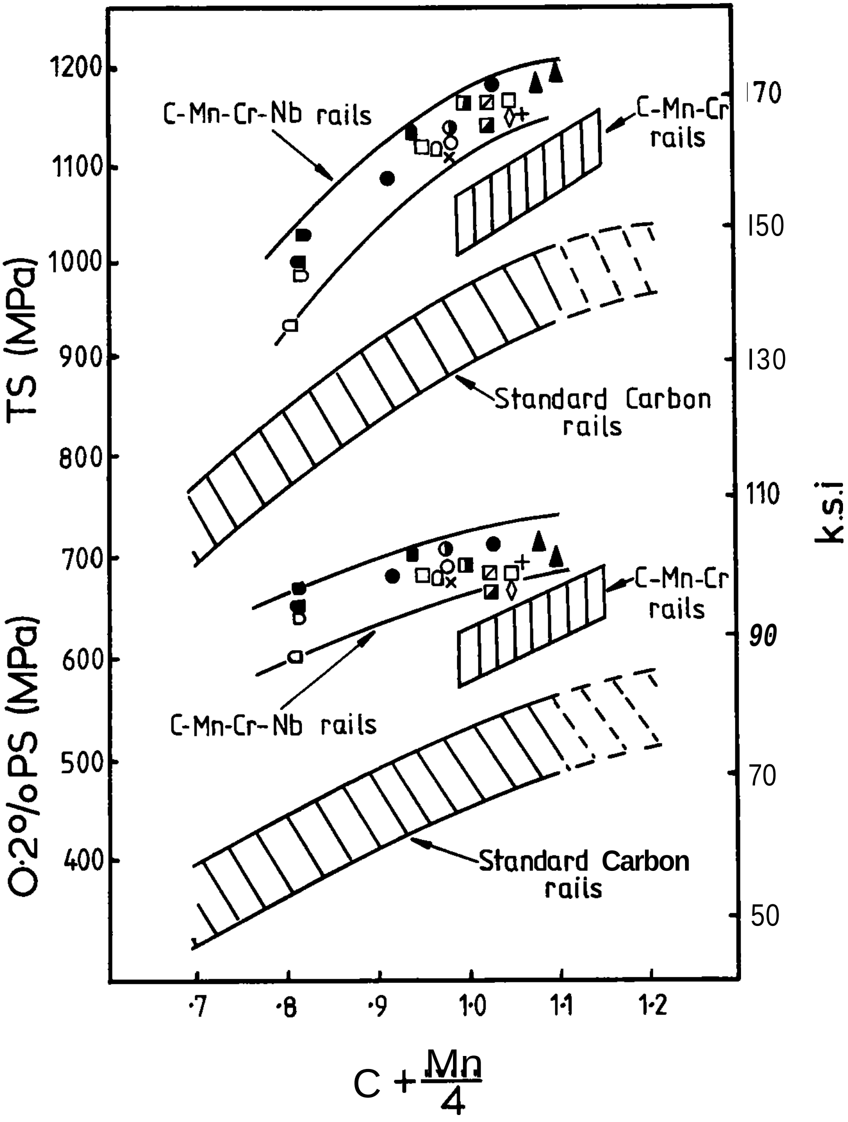
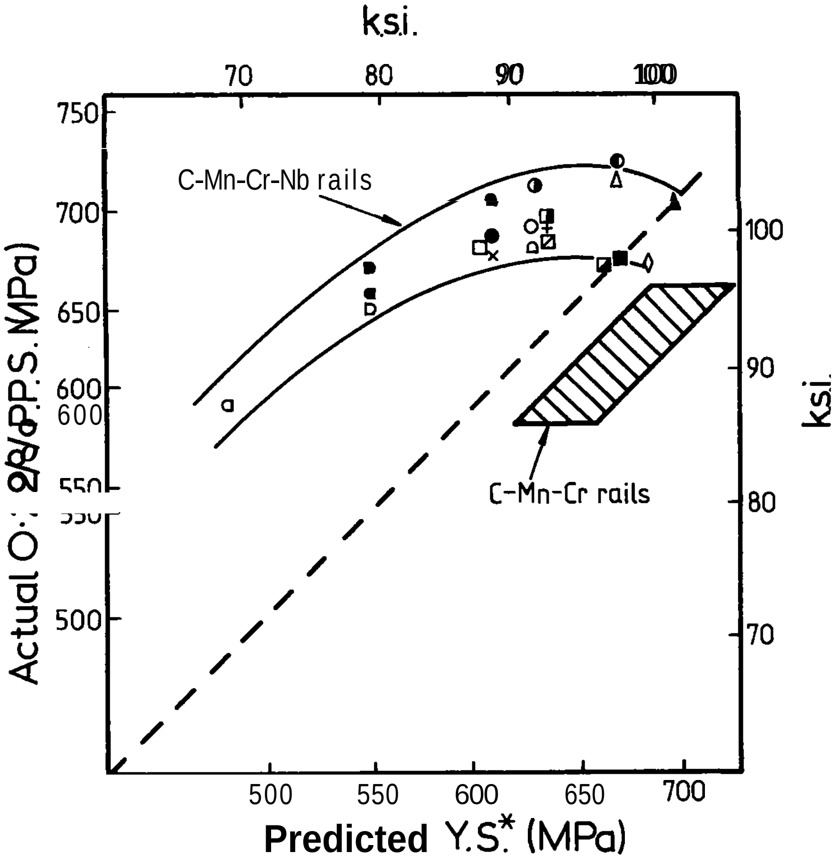


Figure 3. Comparative strength of standard carbon, C-Mn-Cr and C-Mn-Cr-Nb rails manufactured at AIS plotted against C + Mn/4 (Refer Table II).



* YS=108+474·7%C+0%Si+84·2%Mn+128·3%Cr +0%P (Heller)

Figure 4(a). Actual versus Predicted YS of C-Mn-Cr and C-Mn-Cr-Nb rails.

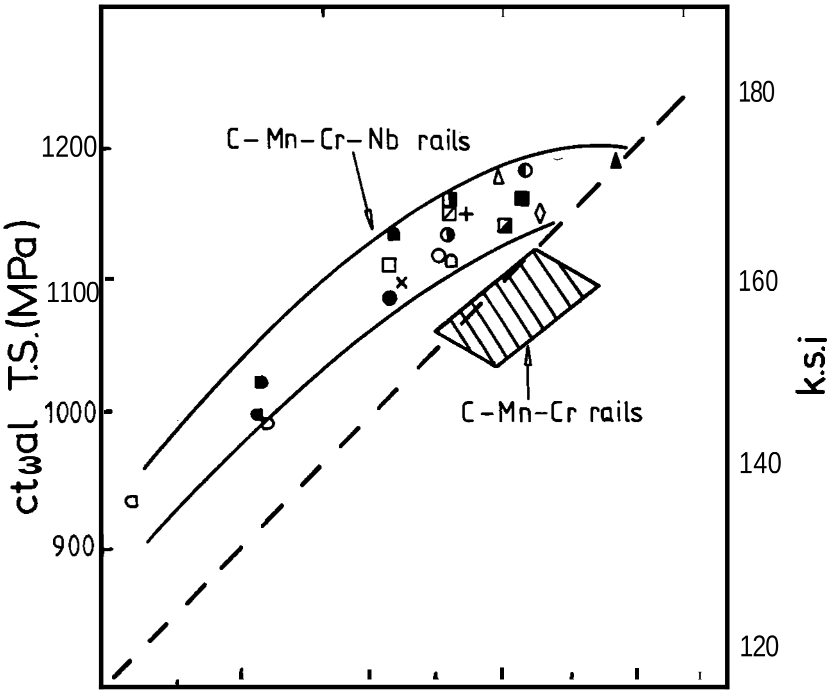


Figure 4(b). Actual versus Predicted TS of C-Mn-Cr and C-Mn-Cr-Nb rails.

steels suggests that the equations of Heller and Schweitzer over-estimate yield strength by about 50 MPa (7 k.s.i.) and tensile strength by about **25** MPa (3.5 k.s.i.) for the manufacturing and processing conditions used at AIS. A plot of Δ yield strength and Δ tensile strength (where Δ = actual - predicted) versus carbon content is shown in Figure 5 (a) (b), and highlights the reduced strengthening capacity of niobium at higher carbon content. At carbon contents above about *0.80* percent there is little difference between actual and predicted strengths when the approximate correction factors of 50 MPa (7 k.s.i.) and **25** MPa (3.5 k.s.i.) are applied to yield strength and tensile strength respectively.

The effect of niobium content on yield and tensile strength is shown in Figure **6** (a) (b), in terms of normalized parameters, YS/CE and TS/CE, which take into account variations in base composition (viz CE = C + Mn/4 + Cr/5). Again, the effect of niobium on strength properties is shown to be governed by carbon content. However, irrespective of carbon content, there appears to be little strengthening benefit in adding niobium at levels in excess of about *0.030* percent. While the strengthening effect of niobium diminishes with increasing carbon content, ductility, as measured by total tensile elongation is apparently improved for the range of carbon contents produced at AIS *(0.43* to 0.82 percent). In Figure 7 the product of tensile strength and elongation (TS.El/1000) is significantly higher for niobium steels than for standard carbon rails. While conventional C-Mn-Cr rails (without niobium) generally appear somewhat better than average standard carbon rails in this respect, they do not usually match the niobium steels. It is well known that in pearlitic steels, the strength is increased with a reduction in interlamellar spacing and that ductility is improved by a refinement in pearlite colony size (8, ***24).*** Manganese and chromium additions achieve both of these effects (25, ***26).*** However, in work carried out at BHP Melbourne Research Laboratories on C-Mn-Cr-Nb rail steels ***(27)*** it has been shown that the main microstructural effect of niobium is to further refine the pearlite colony size with no significant effect on the interlamellar spacing (Figure 8). Since the latter has a major controlling effect on the strength of pearlitic structures, it would therefore appear that the higher strengths achieved in niobium bearing steels are due primarily to precipitation hardening in pro-eutectoid ferrite and the ferrite lamellae. In addition, it is postulated that the improved ductility of niobium rail steels relates to the effect of strain induced precipitation of niobium carbonitride in austenite on the subsequent refinement of the pearlite colony size. It is also likely that the higher strength and finer pearlite microstructure of niobium bearing C-Mn-Cr type rails contribute to their observed longer life in heavy duty applications.

Fatigue and toughness

It is generally accepted that the fatigue endurance limit of steels increases with increasing tensile strength (28). S/N curves determined at BHP ***(29)*** under uniaxial tension/compression conditions have clearly demonstrated that C-Mn-Cr-Nb steel has a fatigue strength of about ***240*** MPa ***(35*** k.s.i.) higher than for standard carbon rail. In addition, microstructural factors and non-metallic inclusions have also been claimed to have significant effects on fatigue in pearlitic rail steels. For instance, fine pearlite is thought to provide greater resistance to localized plastic deformation which is desirable for preventing fatigue crack initiation **(30).** The presence of grain boundary ferrite is also claimed to reduce fatigue crack

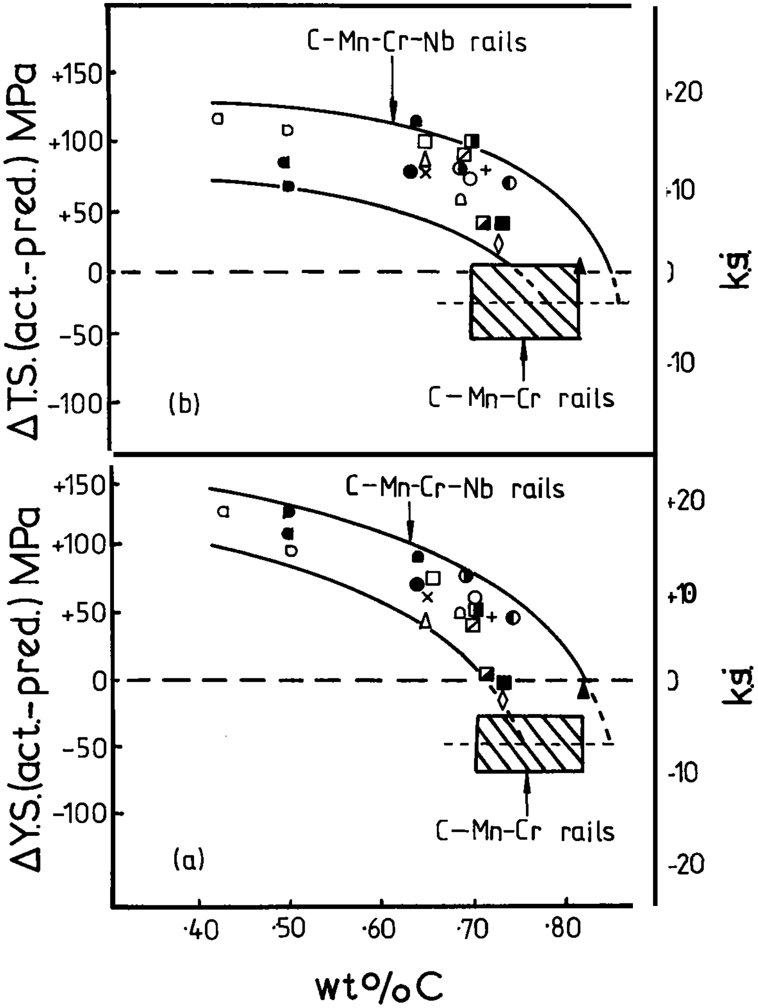


Figure 5(a)(b). Effect of carbon content on strengthening capacity of Nb in C-Mn-Cr rail steels.

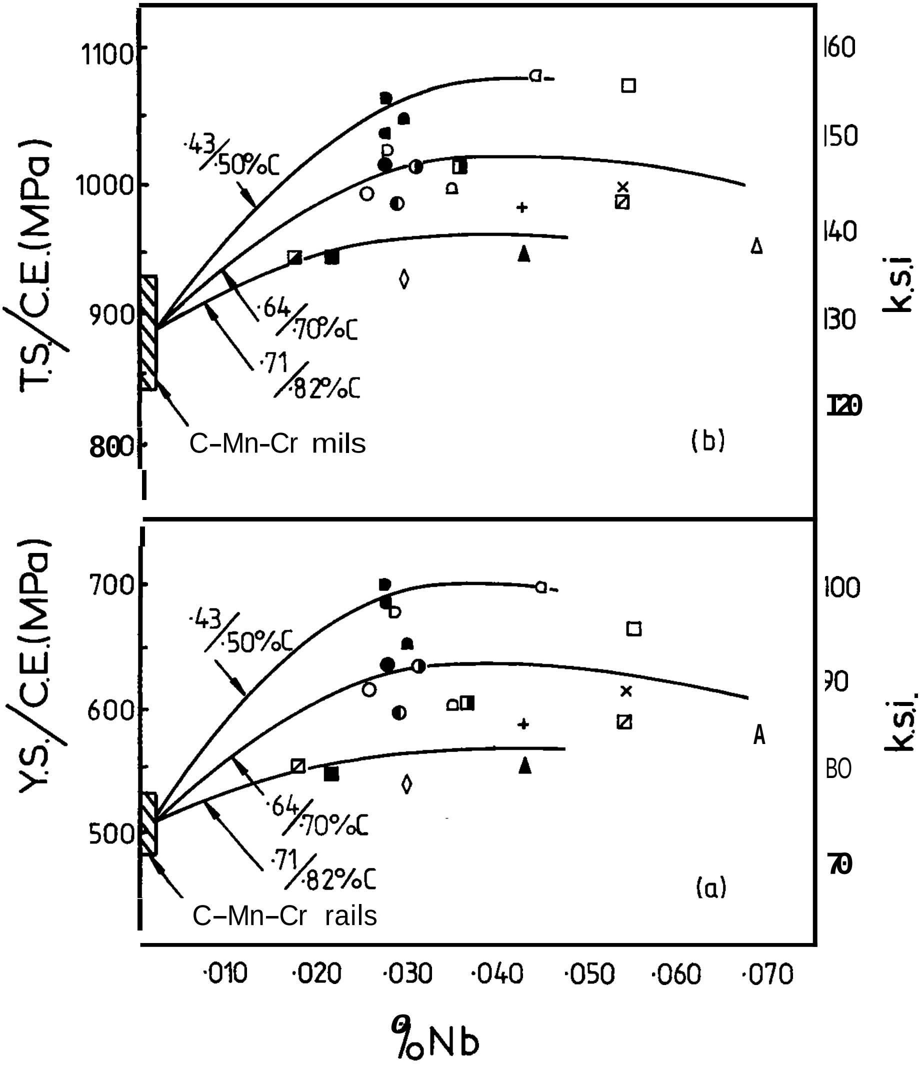
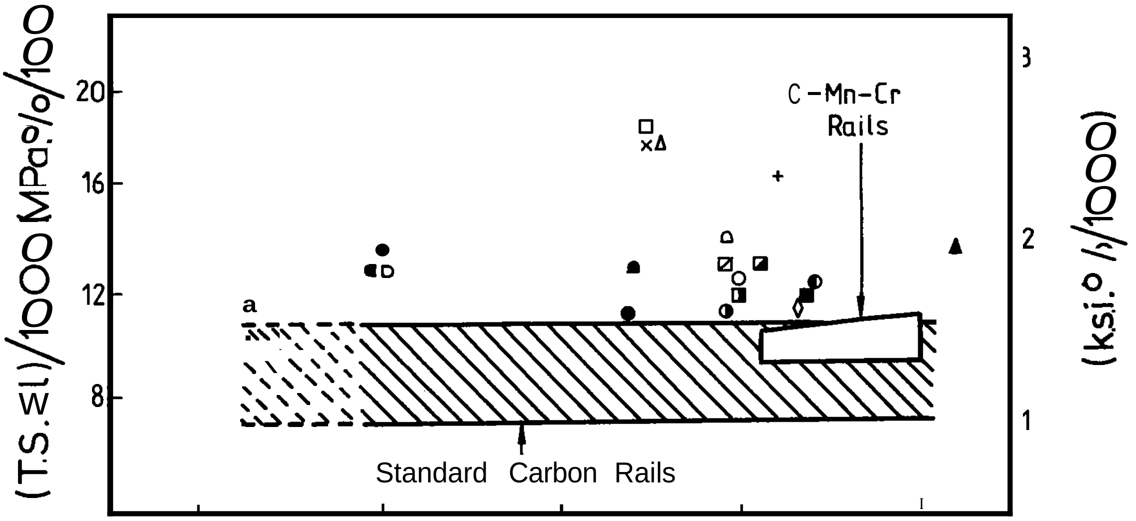


Figure 6. Effect of niobium content on (a)YS/CE and (b)TS/CE in C-Mn-Cr-Nb rails. (CE = C + Mn/4 + Cr/5).


(T.S.×El)/1000 MPa.%
20
16
12
8
(ksi.%/1000)
3
2
1
a
C-Mn-Cr Rails
Standard Carbon Rails

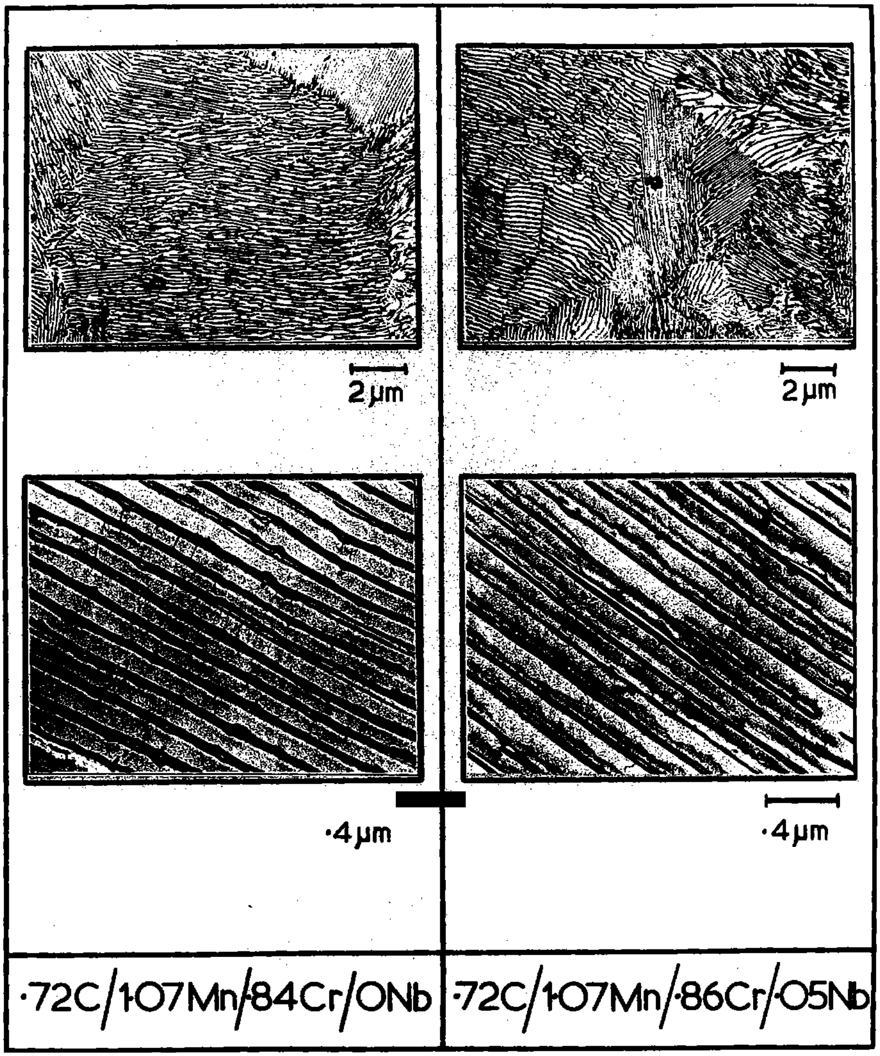


Figure 8. Replica electron micrographs demonstrating reduced pearlite colony size but similar interlamellar spacing of C-Mn-Cr-Nb steel in comparison to C-Mn-Cr steel.

growth rates in carbon rail steels (31). Thus, in addition to higher tensile strength, the fine pearlite and the presence of grain boundary ferrite in lower carbon steels, may also contribute to improved fatigue properties in C-Mn-Cr-Nb rails.

With regard to toughness, it has been suggested that reduced carbon content and finer prior austenite grain size result in increased toughness (24). This would seem to be a plausible explanation for the better performance obtained for low carbon (0.50%) Mn-Cr-Nb rails compared to high carbon (> 0.70%) in gag pressing at AIS.

Weldability

The welding of rails is usually accomplished by flash butt welding a number of individual rails into longer lengths which are laid in track and finally joined insitu by thermite welding. Performance of rails in flash butt welding is more critical than thermite welding because of the much higher cooling rates which are obtained in the heat affected zone (32).

Knowledge of the transformation characteristics of alloy rail steels is therefore of importance in determining the maximum post weld cooling rates desirable to avoid the formation of detrimental transformation structures such as martensite. Hard welds will form high spots in track which can lead to deterioration of rolling stock, rails and ballast and, in addition, may be dangerously brittle.

Continuous cooling transformation (CCT) diagrams of temperature versus time have been determined at BHP Melbourne Research Laboratories for standard carbon, C-Mn-Cr and C-Mn-Cr-Nb steels (27). In terms of Kp values, i.e. the minimum time required by the steel to transform to a microstructure containing 100 percent pearlite in the transformation range 800 to 500 C, it can be seen in Table III that manganese and chromium additions produce a substantial increase in hardenability but that further addition of niobium has little further effect on hardenability.

In flash butt weldinp, the time required to cool from 800 C to 500 C is generally of the order of 300 to 450 sec. Thus, C-Mn-Cr-Nb steels may be welded with little or no interference to the natural cooling rate to achieve fully pearlitic structures in the heat affected zone.

Thermite welds, on the other hand, cool from 800 C to 500 C in about 850 sec and therefore pose no problems with respect to formation of hard phase transformation products. Typical hardness gradients across thermite welds of standard carbon, C-Mn-Cr and C-Mn-Cr-Nb rail steels produced at AIS are shown in Figure 9. The behavior of the niobium bearing steel is similar to that reported for other microalloyed rails (17).

Conclusion

The strengthening capacity of niobium in hiph carbon steel$ is governed by the carbon content, soaking conditions prior to rolling and the finish rolling temperature. Yield and tensile strengths may be increased by up to 70–100 MPa (10–15 k.s.i.) in C-Mn-Cr rails with niobium additions of about 0.03 percent. The strengthening mechanism appears to be precipitation hardening of niobium carbonitride in the pro-eutectoid ferrite and ferrite lamellae in pearlite. In addition, ductility improvements may be effected through the austenite grain refining action of niobium in hot rolling leading to a reduction in pearlite colony size.

Steel	Kp* (sec)
.71 C, .80 Mn, .15 Si	~ 18
.71 C, 1.18 Mn, .23 Si, .91 Cr	~ 250
.72 C, 1.12 Mn, .19 Si, .93 Cr, .07 Nb	~ 275

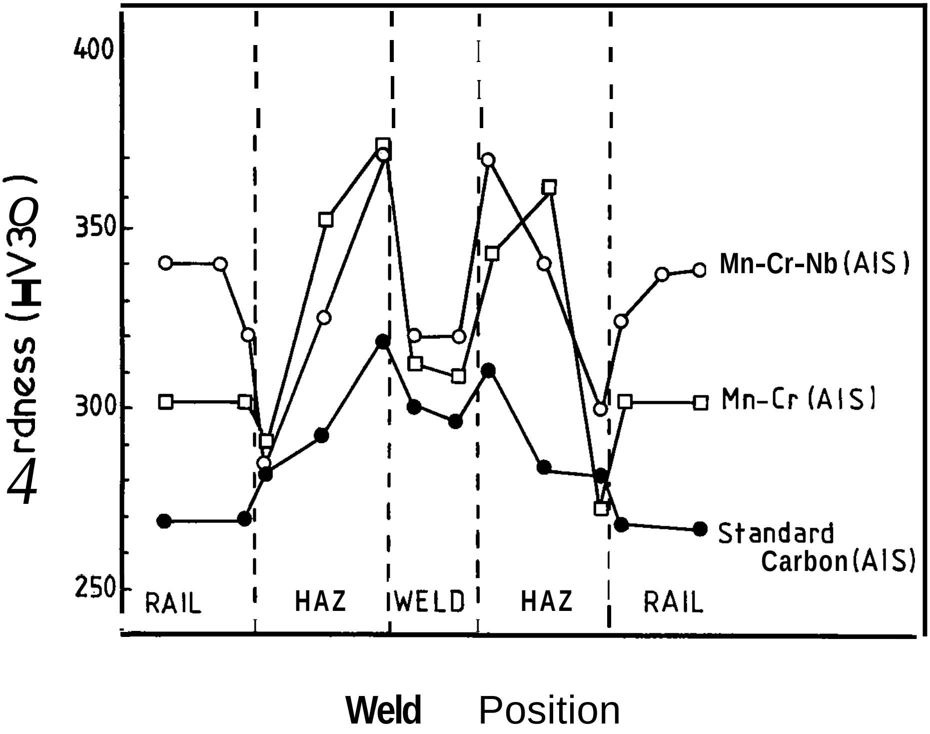


Figure 9. Hardness gradients across thermite welds in Standard Carbon, C-Mn-Cr and C-Mn-Cr-Nb rails.

Through appropriate attention to compositional and processing aspects, the microstructural modifications achieved by microalloying additions of niobium may result in significant improvements in the service performance of rails in heavy duty applications.

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