THE PERMATRACK PROCESS FOR HEAD-HARDENING OF RAIL STEEL

THE FIRST DECADE

A SUMMARY

THE PALADIN GROUP

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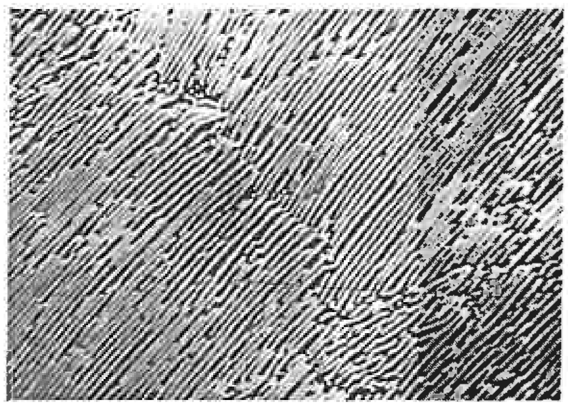

THE FIRST DECADE
A SUMMARY

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THE DEMANDS ON A RAILWAY SYSTEM

In any developed railway system in the world, the cost of replacing worn or defective rails is a major economic consideration. The labour cost as well as the cost of replacement rail for one mile of track is considerable. In addition, a fractured rail is a serious threat to the safe operation of a railway. Selection of the optimum material for a railway system is thus of paramount importance but the decision can only be made with a full understanding of the intricate relationship involved in wheel/ rail contact and the environments which are imposed on this contact. The economic necessity for heavy wheel loading of unit trains carrying such commodities as metal ores, potash, coal and grain under severe weather conditions, which increase the difficulty of effectively lubricating curved track, magnifies the contact problem. With the advent of unit trains for the transportation of bulk materials in Canada on the Canadian National Railway and the Canadian Pacific Railway in the late 60's, the rail problem spread beyond the iron ore roads for the first time. The Canadian National Railway system experienced a 50% increase in average load between 1965 and 1975 (Figure 1). The railway industry began then to earnestly attack the subject of increasing wear rates when it became apparent, in the late 70's, that standard rail chemistries would no longer meet the demands of increased car capacities (Figure 2).[1]

The railroad rail must bear the loads transferred to it by the wheels while at the same time acting as a guide over the many miles of track. Service stresses in the rail can result from the forces imposed on it from the rolling practice in the form of static residual or thermal stresses or from the dynamic forces which occur as a result of the impact during wheel/rail contact. When the load imposed at the wheel/rail interface is subjected to adverse conditions such as curves, the concentrated loads on the gauge corner of the rail cause plastic flow which results in significantly different wear patterns on the outside and inside rail (Figure 3).

At the end of the service life on curved trackage the outer rail (high side) is severely worn on the gage side of the rail and is typically shelled at the gage corner. The inner rail (low side) experiences substantial plastic flow of metal toward the field side and the surface of the rail is flaked along the width of the head. The removal of rails for side head wear has increased three-fold, in Russia as an example, in the five year period between 1988 and 1993 (Figure 4)[2].

Demand for high strength, wear resistant rails which have a homogenous structure and good welding characteristics, is one that will continue into the next century for two reasons:

1- Quantities of raw materials will, of necessity, still need to be transported over considerable distances for processing or shipping - increasing axle loads will thus remain a source of concern.

2- Local geography will continue to impose the needs to use curves of small radius which will cause severe track wear.[3-5]

Rail development priorities have taken various paths in the past twenty years because of individual railway needs and specific track conditions in each world sector (Table 1). The track environment in North America, for example, differs in many respects from that of Europe, Asia and elsewhere. Even as late as the early eighties, axle loads were limited to 18 tons in Italy, 25 tons in Britain and 20 tons in Germany as compared to 35 tons and higher in North America. Also, the European rail community rarely regard softwood ties as practical with most using concrete or hardwood.

For the next quarter century, then, rail will be required to meet even increasing demands of fatigue/fracture resistance and wear. The most effective means for controlling the fatigue problem (flaking, shelling and spalling) will be the use of clean steels at the manufacturing stage and rail grinding at the maintenance stage. Lubrication of rail after track laying will prolong wear life and rail manufacturers can do their part to increase wear performance by the use of metallurgical practices which produce high hardness levels in fine pearlitic steels.

THE SYDNEY STEEL CORPORATION AND THE PERMATRACK PROCESS FOR HEAD HARDENING OF RAILS.

The Sydney Steel Corporation (SYSCO) is a rail producer. Since the turn of the century it has supplied the majority of rails for the Canadian railway network. In the international market, SYSCO has earned a well-deserved reputation for product quality and service. SYSCO is the largest exporter of rails on the North American continent and has a proven record over a complete range of operating, climatic and geographic conditions, with the Company manufacturing rails to all major and international specifications. SYSCO has exported over 1,000,000 tons of rails to Mexico in the past twenty-five years as part of that country's transportation development program. In the past quarter century, shipments have been made to Chile, Jamaica, Pakistan, Argentina, Venezuela, Israel, Poland, Malawi, Peru, Abidjan-Niger, Costa Rica, Tanzania, Cameroon, Russia, Korea, Saudi Arabia, Germany, the United States, Mexico, Mozambique, Bangladesh, Indonesia and India.

By the mid '80's it was becoming more apparent that, largely because of the fear of producing martensite in alloy rails, rail suppliers would turn to head-hardening as the means of providing the railways with the most cost effective rail for the foreseeable future. To meet the railway demands and to include a head-hardening process in the $275 million dollar modernization program which began in 1988, the Sydney Steel Corporation examined rail specifications around the world that included AREA, BS II, UIC 860, and those of the Canadian railways and travelled internationally to monitor available technologies with a mission to choose a process that would use the existing specification chemistries of carbon, manganese, chromium and silicon and ensure a rail head-hardness between 325 and 400 BHN. Pearlite spacing in the finished rail, modified by an acurate computer-controlled heating and cooling process, could give the desired hardness within this range.

The selected process, patented under the Permatrack trademark, has employed a unique heating and quenching process incorporating an Ajax Magnathermic induction coil full-depth process which has enabled the corporation, since installation, to precisely control structure, grain size and metallurgical properties and produce a rail that is unrivalled in competing technologies. The end result is a virtually stress-free rail requiring little or no further roller straightening and exhibiting exacting hardness patterns that can meet the most stringent international specifications.

PERMATRACK HEAD HARDENED RAIL – FIRST DECADE RESULTS

1) RAIL PROPERTIES AT THE MANUFACTURING STAGE

To combat the combination of fatigue and wear resistance all head hardening processes must address three concerns – fracture toughness, residual stress and hardness. The Permatrack process, installed at the Sydney Steel Corporation, produces exceptional rail properties (Table 2) and directly address the main concerns;

(A) Fracture Toughness

It has been reported by Orringer et al [6] that today's rail has a Kic value between 25 and 50 ksi √in. The average Sydney rail Kic has been determined by Canmet in Ottawa and Ortech International in Mississauga, Ontario to be 63 ksi√in.[7]

Igwemezie in his report on the evaluation of Sydney Steel head hardened rail states [8]:

> " Sydney Steel rails have a toughness reserve in excess of 170 per cent when the maximum tip stress intensity (23 ksi√in) we measured is compared to the measured fracture toughness value of 63 ksi√in. Hence residual stress and catastrophic rail failure should not be expected from the rail because of adequate fracture toughness reserve."

(B) Residual Stress

During roller straightening of rail the head and base section go into longitudial residual tension while the web section goes into longitudinal compression and vertical tension. In the early stages of bringing the Permatrack process into operation at the Sydney Steel Corporation, Igwemezie concluded that [9]:

> " Our experience to date with saw cutting rails shows that rails out of the Sydney Steel Mill have the smallest variation in saw cut openings at all locations. This indicates very good control of the stress in the rail during the hardening and cooling processes."

(C) Hardness

The Association of American Railroads have established a relation between gage face wear and measured Brinell hardness of the rail.[10] Trials at the FAST track in Pueblo, Colorado indicate that levels of hardness above 350 are necessary to ensure improvement over standard carbon rail (Figure 5).

Head-hardened rails manufactured at the Sydney Steel Corporation are designed to meet the railways specification of the Canadian National Railways– one of the most demanding requirements in the railway industry. To permit wear up to 22 MM into the rail from the running surface the specification insists on an average reading of not less than 363 BHN in five locations around the radius of the head (Figure 6) and with no single reading less than 352 BHN.

In addition, reading taken at a point 22mm. from the running surface of the rail (point 0) cannot be less than 344 BHN. Also readings, taken at 10mm intervals to a depth of 62mm, must show a gradual decrease in the hardness of the rail moving away from the top surface of the rail with no sharp drop or discontinuity in the hardened zone in the head or at the head-web intersection.

2) IN SERVICE PERFORMANCE

The in service performance of a number of rail corporations and manufacturing practices was the subject of an intensive Canadian railway study in the early 90's. The conclusions reached indicated conclusively that, in both the low and high rails, head loss was substantially reduced when head hardened rail was used in place of standard rail in curves from two to eight degrees. Comparison figures indicate a performance ratio from 2-3 to 1 in the high rail (Figure 7) to 5-6 to 1 in the low rail (Figure 8).

The Sydney Steel Corporation has now supplied head-hardened rails to meet the needs of railways in North and South America, Europe and Asia, in sections from 100 to 136 lbs/yd and for applications from transit systems to heavy haul railways carrying iron ore from mine to port.

There are no indications of premature wear from any of the railroads currently using rail supplied from the Permatrack process and repeat business is becoming a standard practice as new purchasers replace rail from other international suppliers by rail produced by the Permatrack process. The ability of the patented process to produce rail consistently between 350 and 400 Brinell hardness will ensure that this rail will maintain a leading position in the head hardened rail supply industry. Norm Hooper, Chief Engineer of the British Columbia Railway, perhaps sums up the added value of the rail produced by the Permatrack process when he states, [11]

> "The Sydney Steel rail provides us with the opportunity to get bonus value such as the low residual stress in the rail - for our demanding loads and curvature, factors such as that are important."

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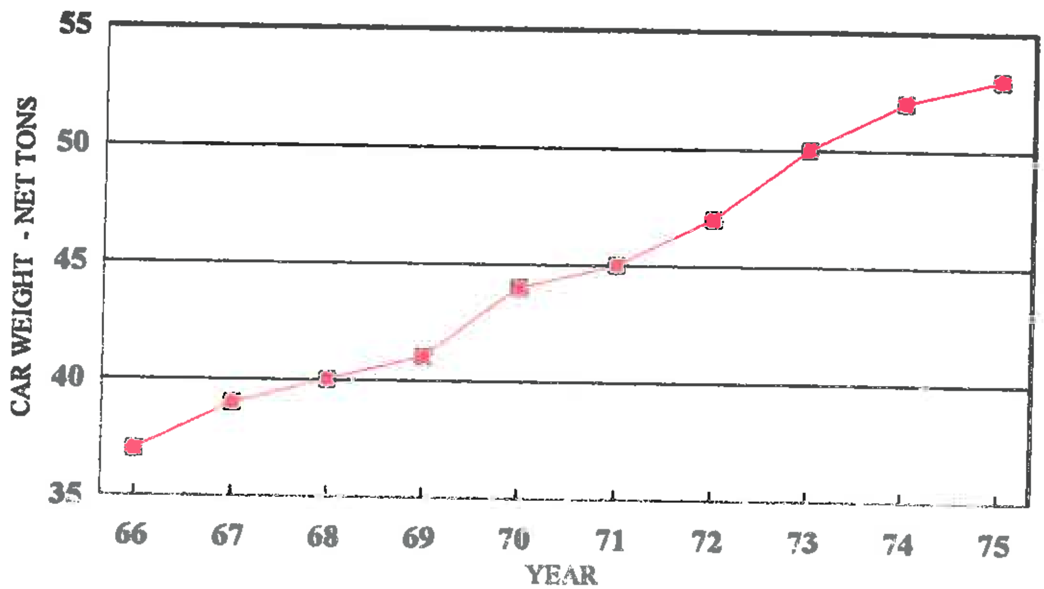


FIGURE 1: CAR WEIGHT - AVERAGE LOAD ON CANADIAN NATIONAL RAILWAY SYSTEM

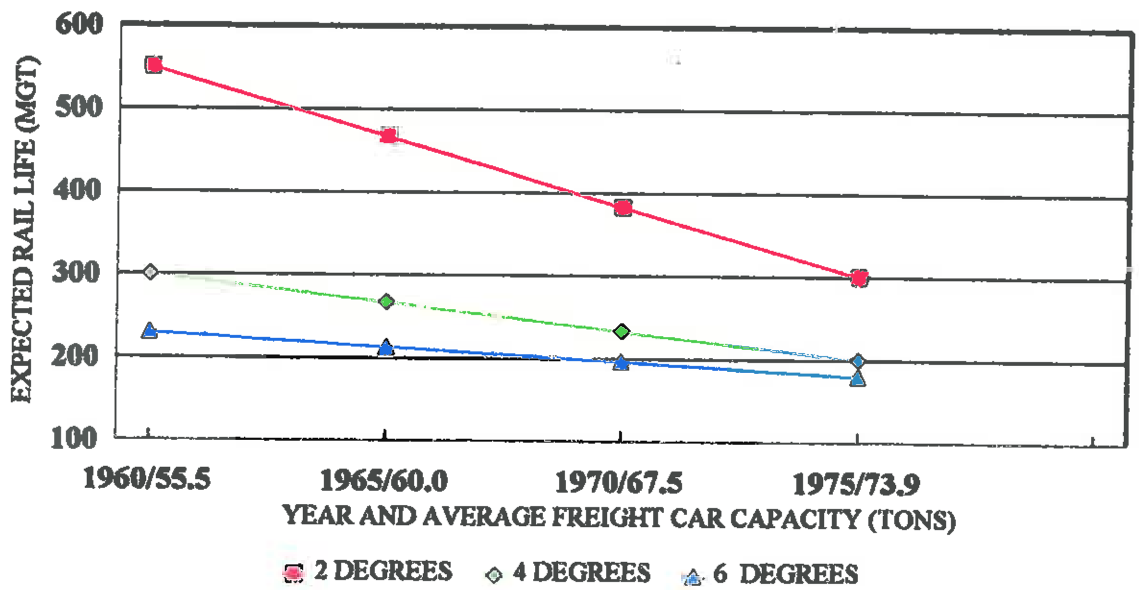
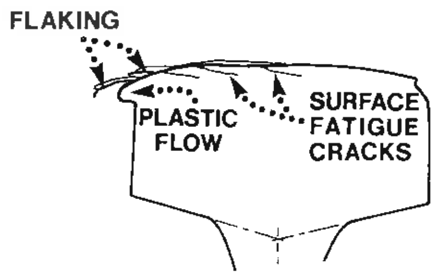
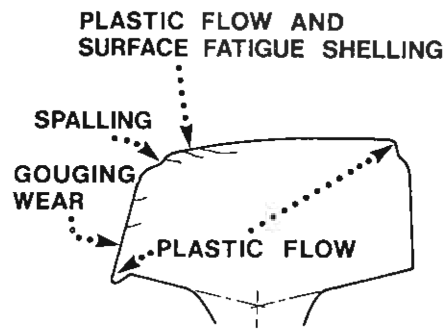


FIGURE 2

RAIL LIFE (MGT) IN CURVES FOR CAR WEIGHTS (1960 - 1975)



INNER RAIL
(Low Side)



OUTER RAIL
(High Side)

FIGURE 3

TYPICAL RAIL WEAR IN CURVED TRACKAGE UNDER HEAVY TRAFFIC CONDITIONS

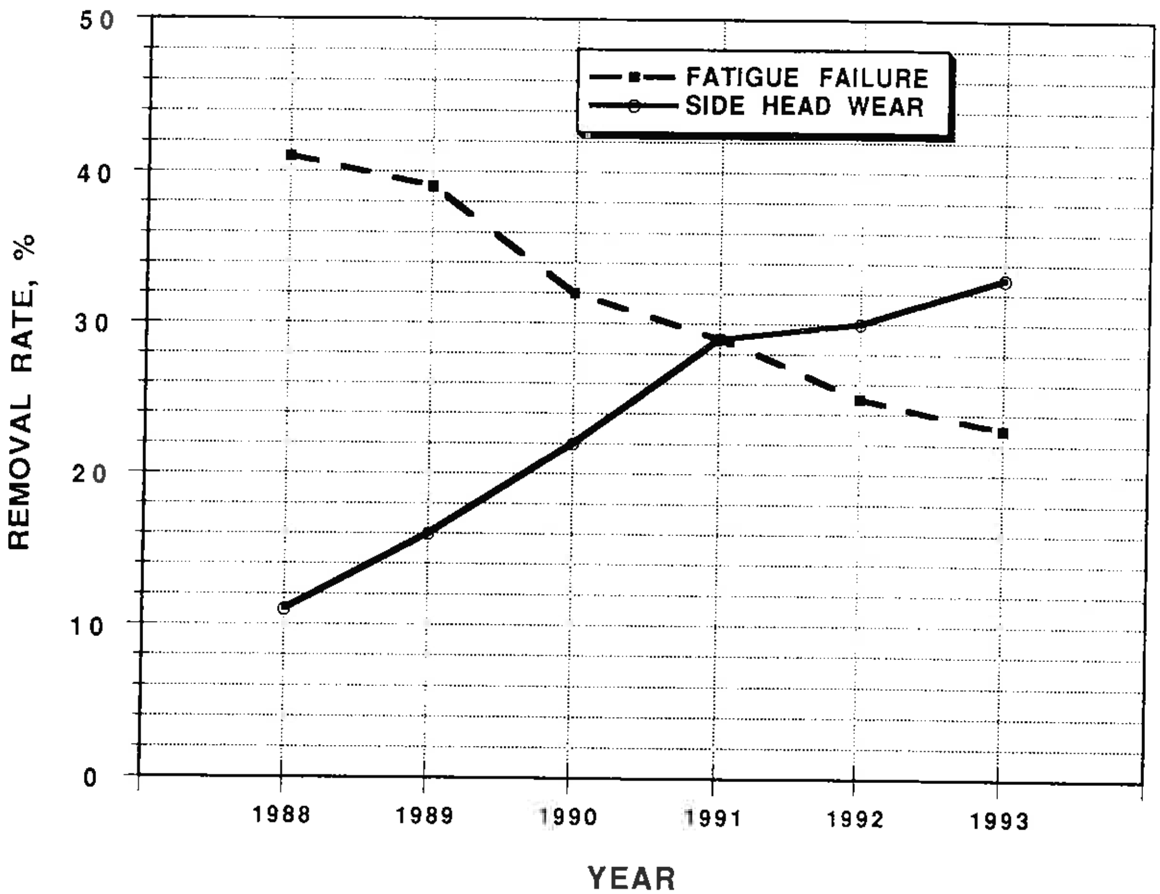


FIGURE 4

RATE OF RAIL REMOVAL FROM RUSSIAN NETWORK (1988-1993)

TABLE 1
PREMIUM RAIL STEELS
(INTERNATIONAL MARKET)

RAIL TYPE		CHEMICAL ANALYSIS							MECHANICAL PROPERTIES				
		C	Si	Mn	Cr	Mo	V	Nb	0.2 PS (Mpa)	TS (Mpa)	Elon. %	R A %	Country of Origin
Alloy	Hi - Si	0.75	0.65	0.80					520	980	11	14	USA
Alloy	Cr	0.75	0.35	1.25	1.15				690	1,130	11	17	U.K.
Alloy	Cr - V	0.75	0.30	1.30	0.80		0.12		740	1,230	10	15	Australia
Alloy	Si-Cr -V	0.65	0.60	1.05	1.15		0.20		680	1,130	12	20	Germany
Fully Heat Treated	Through Hardening	0.80	0.20	0.90					870	1,220	13	30	USA
Fully Heat Treated	Through Hardening	0.75	0.30	0.90					820	1,250	14	40	USSR
Head Hardening	Head Hardening	0.65	0.20	0.90					830	1,140	17	50	Japan

A.R.E.A. SPECIFICATION REFERENCE
Standard Carbon

C	Si	Mn	Cr	Mo	V	Nb	0.2 PS (Mpa)	TS (Mpa)	Elon %	R A %
0.80	0.20	0.90					510	920	11	18

TABLE 2

HEAD HARDENED RAIL (PERMATRACK PROCESS) PROPERTIES

METALLURGICAL PROPERTIES	MEAN VALUE
Hardness (BHN)	
Running surface	390
Average A–E	370
Average O	350
Yield strength (LBS / in ^{2})	125,000
Tensile strength (LBS/ in^2)	185,000
Elongation (%)	12.5
Reduction of area (%)	36.5
Residual stress (MM)	-1.5

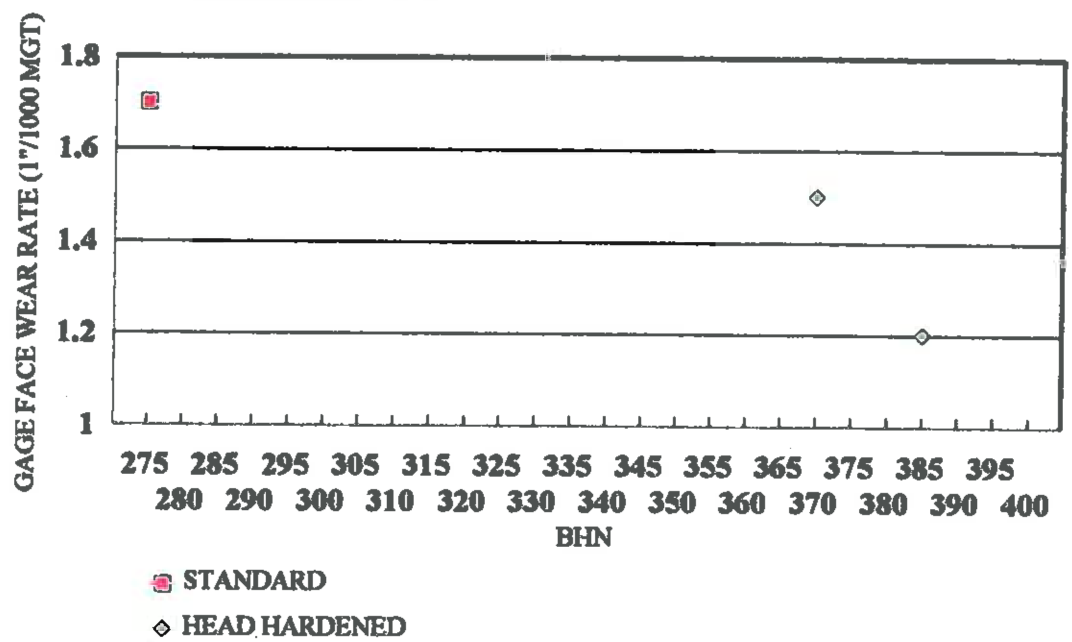


FIGURE 5: HIGH RAIL GAGE FACE WEAR RATE WITH RESPECT TO BRINELL HARDNESS FOR STANDARD AND HEAD HARDENED RAILS

20.2.2 Hardness Depth: One rail from each heat shall be tested for hardness depth. Tests shall be made on a suitably prepared end face by a method approved by the Railway. Readings shall be made on the head section of the rail at the five locations indicated by an "A, B, C, D, E" in Figure 4. The average of the five readings shall be not less than 363 BHN and no single reading shall be less than 352 BHN. If these requirements are not met then five additional readings shall be taken at adjacent points. If these readings are not within the required limits then the rail shall be rejected and the other rails from the heat shall be individually tested and subject to acceptance or rejection on the same basis.

In addition, readings taken at the point marked "0" in Figure 4 shall not be less than 344 BHN.

20.2.3 Hardness Pattern: The same rail shall be tested for the uniformity of the hardness pattern on a suitably prepared end face by a method approved by the Railway. Four readings shall be made along the vertical center line at the locations indicated by an "X" in Figure 4. There shall be a gradual decrease in the hardness of the rail moving away from the top surface of the rail with no sharp drop or discontinuity in the hardened zone in the head or at the head web intersection.

Locations of Hardness Determinations

Figure 4

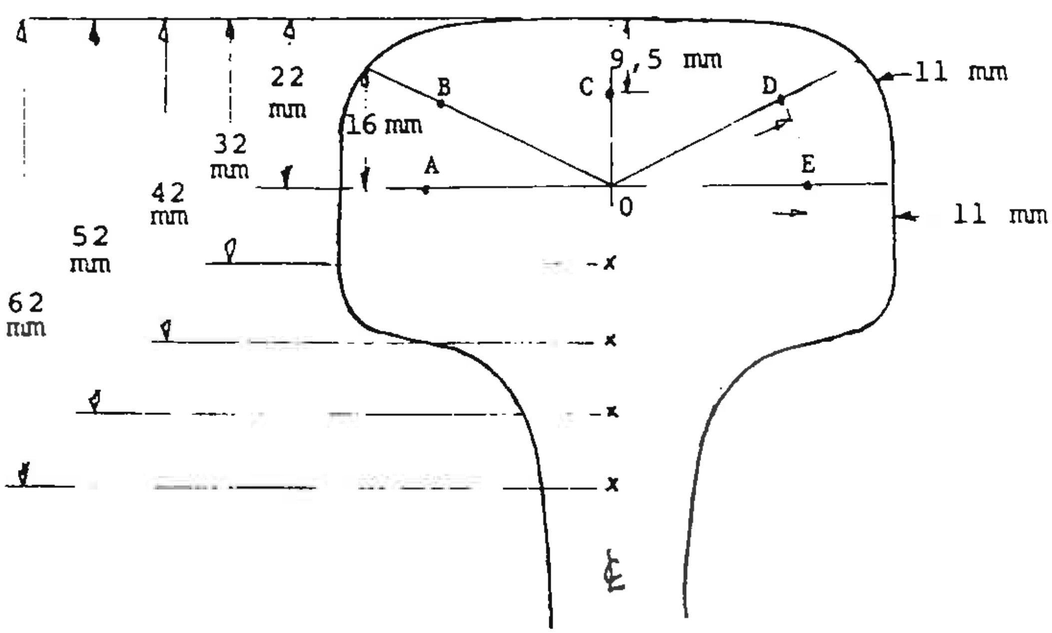


FIGURE 6

CANADIAN NATIONAL RAILWAY SPECIFICATION 12-16 A (SUBSECTION 20.2.2 HARDNESS DEPTH) AND LOCATION OF HARDNESS DETERMINATIONS

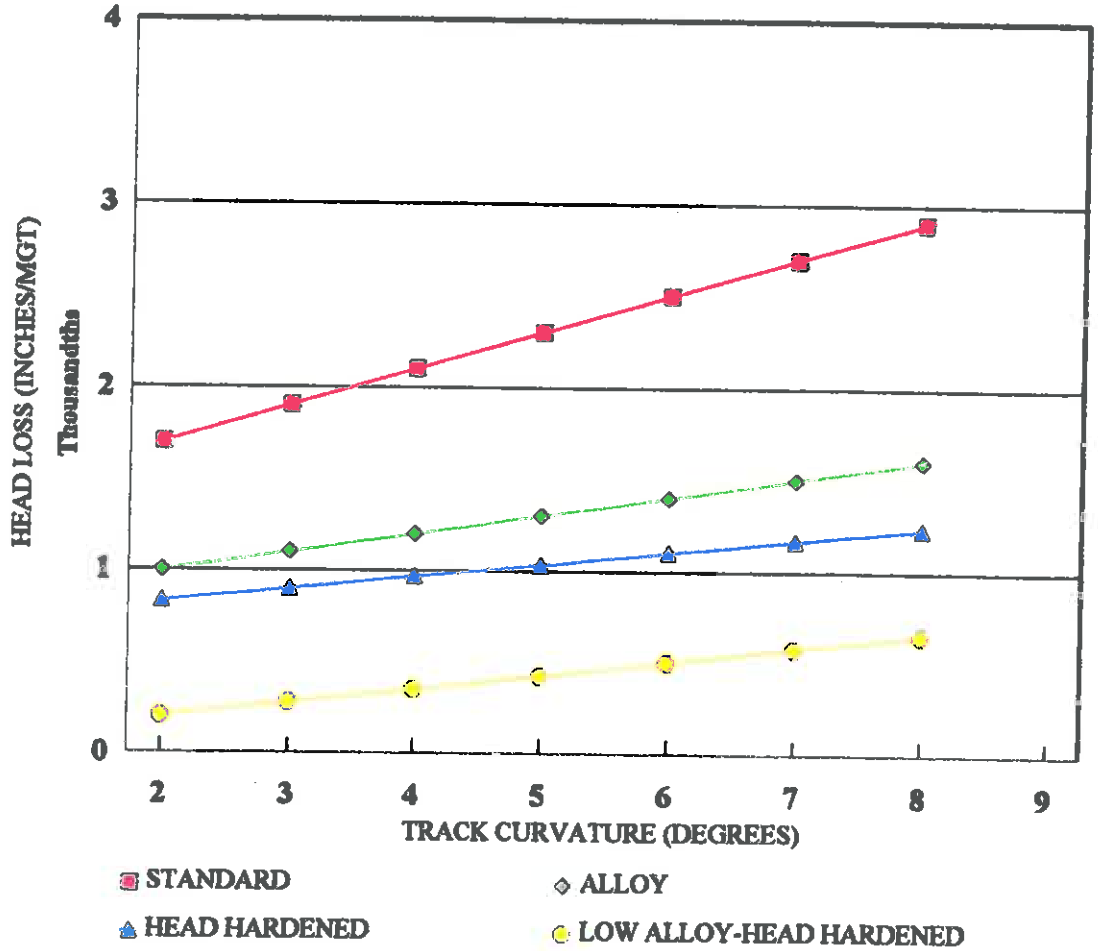


FIGURE 7: HIGH RAIL HEAD LOSS RATE IN TRACK CURVATURE BETWEEN TWO AND EIGHT DEGREES

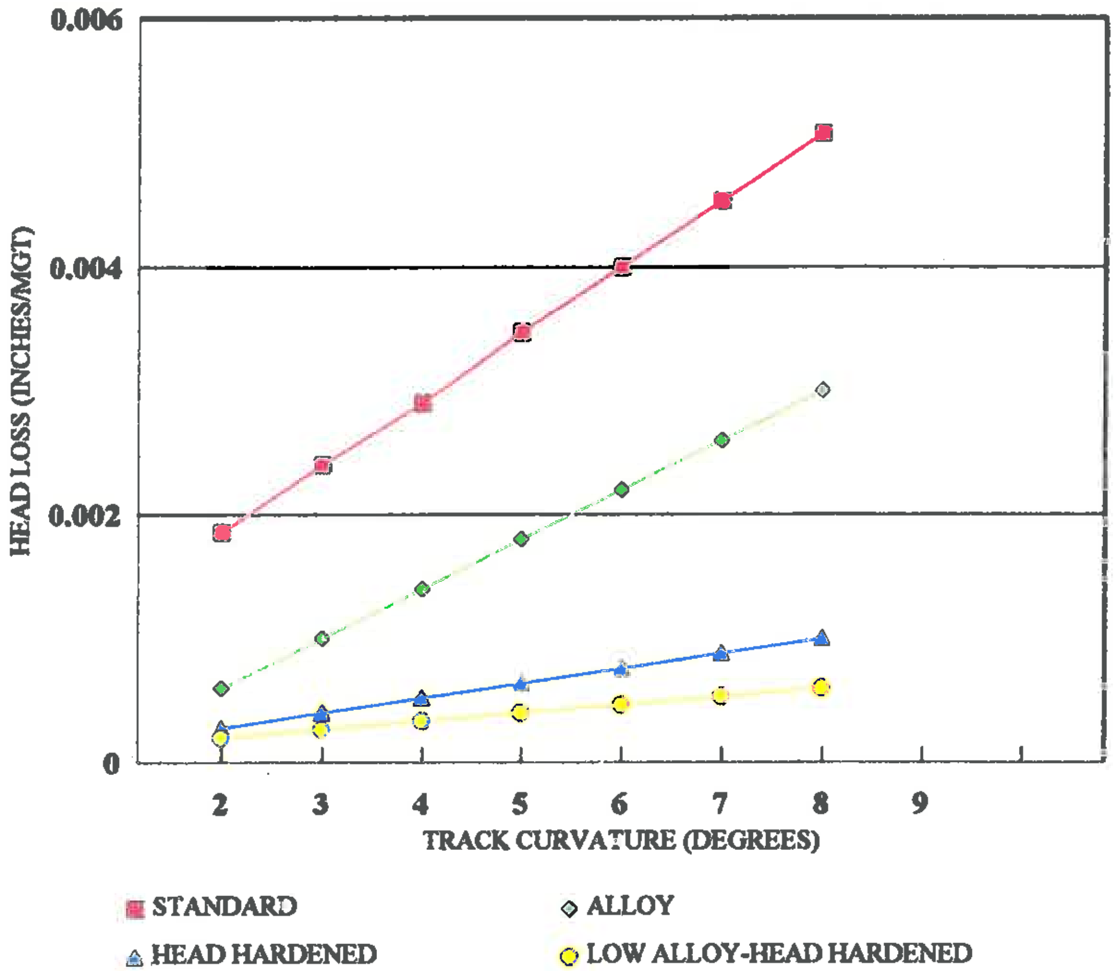


FIGURE 8: LOW RAIL HEAD LOSS RATE IN TRACK CURVATURE BETWEEN TWO AND EIGHT DEGREES