

**KNOWLEDGE  
FOR A BRIGHTER  
FUTURE**

# Properties and applications of Ni-Hard alloys

---

A GUIDE TO THE USE OF  
NICKEL-CONTAINING ALLOYS  
N° 11017

# Properties and applications of Ni-Hard alloys (11017)

A GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

---

Second Edition  
Published 2021

The material presented in this publication has been prepared for the general information of the reader and should not be used or relied on for specific applications without securing competent advice.

The Nickel Institute, its members, staff and consultants do not represent or warrant its suitability for any general or specific use and assume no liability or responsibility of any kind in connection with the information herein.

Updated by: Dr. John Fischer

Edited by: Geir Moe

Cover photo courtesy of Canadian Wear Technologies

# Contents

<b>Introduction</b> .....	5
Abrasion resistance	
Carbon content and microstructure	
Resistance to fracture	
<b>Grades and compositions</b> .....	7
Standard Ni-Hard 1 & 2	
Special Ni-Hard 1 & 2	
Ni-Hard 4	
<b>Production</b> .....	14
Molding and methoding	
Melting	
Casting	
Bimetallic and compound castings	
Heat treatment	
Finishing the castings	
Welding	
Machining	
<b>Mechanical and physical properties</b> .....	23
<b>Testing</b> .....	23
Hardness	
Impact fatigue resistance	
Soundness	
Standards	
<b>Bibliography</b> .....	26



# Properties and applications of Ni-Hard alloys

## INTRODUCTION

For over half a century, Ni-Hard has been the number one choice for industrial processes demanding extreme abrasion resistance. Its well proven, low-cost characteristics have seen it used in the mining, power, cement, ceramic, paint, dredging, coal-coke, steel and foundry industries. As grinding balls, mill liners, pulveriser rings and roll heads, slurry pump parts, pipes and elbows, wear-backs and metalworking rolls – the range of properties inherent in the different grades of Ni-Hard has made it a worldwide success.

Ni-Hard is the generic name for a family of white cast irons alloyed with nickel and chromium to give high hardness and outstanding resistance to abrasion. There are two distinct groups of Ni-Hard compositions:

- Ni-Hard 1 and Ni-Hard 2 with nominally 3.3% and 2.6% carbon respectively, and 4% nickel and 2% chromium
- Ni-Hard 4 with nominally 3% carbon, 9% chromium, 5% nickel and 2% silicon

These three alloys are standardised in almost all industrialised nations under various designations.

### Abrasion resistance

The abrasion resistance of a material is not a distinct property like hardness or tensile strength but depends on the system where abrasion takes place. This so-called tribological system is complex: subtle changes may result in significant changes in service life or relative performance of different materials.

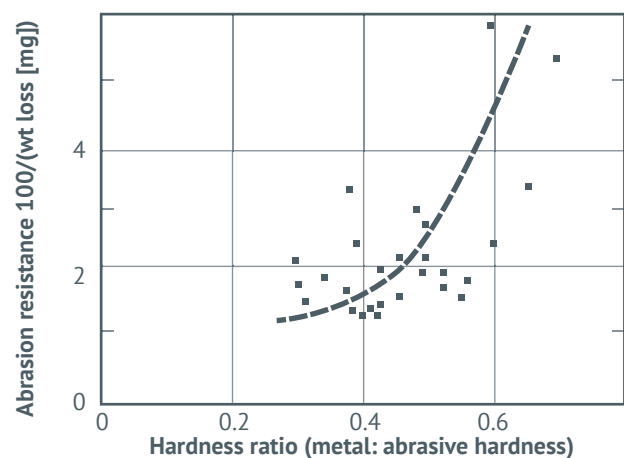
Abrasion resistance cannot be easily measured. The many abrasion tests used or described in the literature do provide valuable insights into the mechanisms of abrasion, but their

results do not allow a calculation or prediction of service. Such tests may be useful tools in research and development of improved abrasion, but at best they give only the correct ranking of various materials in certain industrial applications. There is no general correlation between abrasion resistance and the other properties of the material.

### The relationship between hardness and abrasion resistance

Hardness is usually regarded as an indication of the abrasion resistance of a material. This is approximately correct – especially for a wide range of metals and alloys and if comparatively soft abrasives are considered. But elastomers, for example, behave differently. This is because most abrasive actions involve some scratching or gouging action; a soft abrasive cannot do this to a much harder metal. If the abrasive hardness approaches the hardness of the metal, however, metal hardness becomes less important. *Figure 1* shows how abrasion resistance of white irons changes with the ratio of metal to abrasive hardness.

**Figure 1** Variation of abrasion resistance in a lab test with the ratio of the hardness of white iron to the abrasive hardness<sup>1,2</sup>.



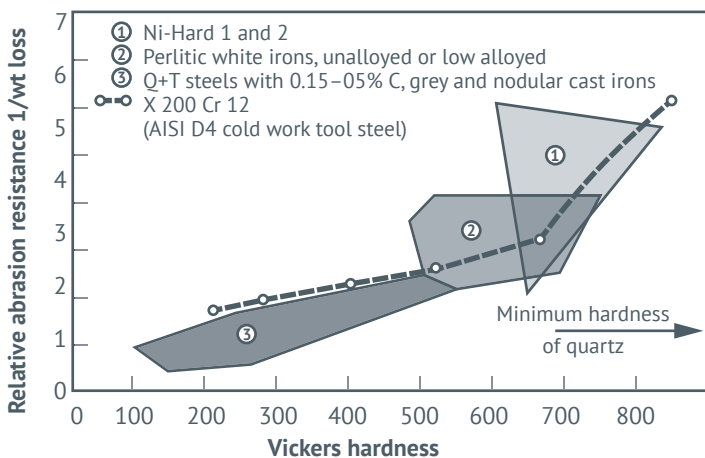
At a high ratio, abrasion resistance is high, but when the ratio drops below 0.6 there is a wide scatter and the slope of the curve indicates the decreasing influence of metal hardness. Unfortunately, many minerals contain quartz or silicates which are as hard or harder than metallic alloys. But even when the abrasive is harder than the metal, increasing metal hardness can still be beneficial – as shown in *Figure 2*. The wide scatter band in both figures indicates that other factors play a role.

There is a much closer correlation if the hardness of the worn and work hardened surface, instead of the original hardness, is considered.<sup>5,6</sup> Although this result is of considerable interest in research, the practical use is rather limited. The work hardening capability of the material depends on the tribological system; this sometimes gives startling results and contradictions between laboratory and industrial results. For example, an austenitic white iron may show outstanding abrasion resistance in a laboratory pin abrasion test with silicon carbide (2,600 DPH) (diamond-pyramid-hardness). In an industrial application, with softer, siliceous abrasives (600 to 1,200 DPH), a martensitic iron will be superior in most cases.

### Carbon content and microstructure

The abrasion resistance of iron and steel correlates reasonably well with their carbon content and microstructure. Generally, abrasion resistance will increase with carbon content, provided free graphite is absent.

**Figure 2** Abrasion resistance of various iron-base alloys as influenced by their hardness. Wear pot test with quartz<sup>3,4</sup>

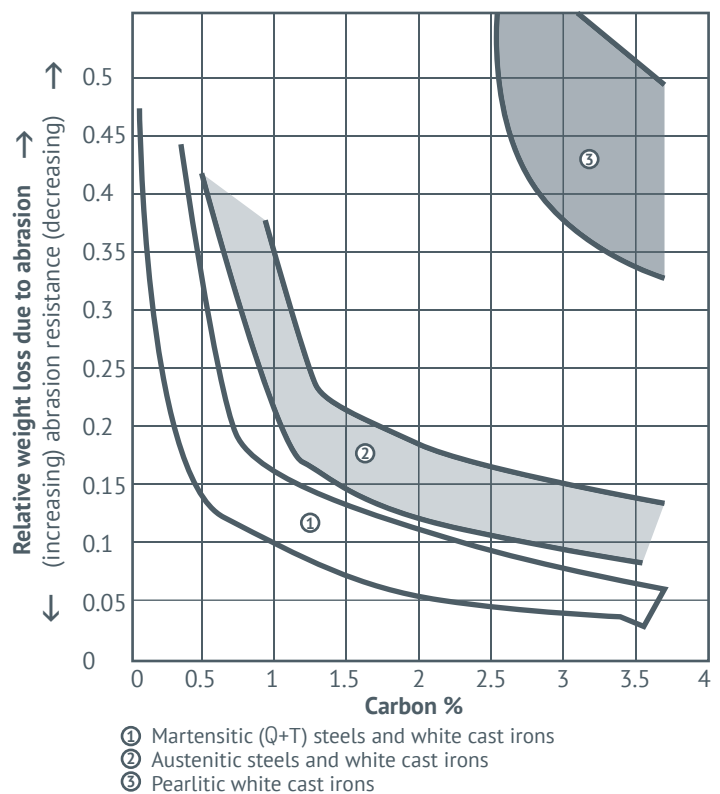


The results in *Figure 3* indicate a dramatic increase in abrasion resistance with carbon content, from low carbon steels to white irons.

At each carbon level, the highest abrasion resistance is achieved by materials with martensitic matrix structures. Their position within the scatter band depends on the heat treatment condition: untempered martensite gives the highest abrasion resistance. Any tempering will reduce abrasion resistance to a much greater extent than indicated by simple loss of hardness. Tempering may occur during work-place usage due to frictional heating.

The second band describes austenitic irons and steels. Their work hardening capability is responsible for their position in the band at each carbon level. Work hardening of an austenitic matrix requires sufficiently high surface stress by impact or high stress abrasion in service. Under sliding or erosive wear conditions, work hardening and the associated increase in abrasion resistance are less likely.

**Figure 3** Abrasion resistance versus carbon content and microstructure of various white irons and steels.



Pearlitic white irons show a rather poor performance despite their high carbon content, because their weak matrix cannot support the brittle carbides because chipping may occur.

The distance between the three fields shown in *Figure 3* depends on the possibility for work hardening. Under conditions of high work hardening, the bands for austenitic and martensitic materials may overlap; some types of alloy white irons can even demonstrate a reversal of ranking. On the other hand, low-stress abrasion will make the pearlitic white irons appear less poor than in *Figure 3*. Generally, the more severe the abrasive condition, the smaller will be the relative difference between various irons and steels.

Since the hardness of each type of iron or steel is increased by raising the carbon content and making the matrix martensitic, abrasion resistance increases with hardness. However, it must be recognised that hardness does not improve abrasion resistance by itself but is meaningful only as an indicator of the microstructure of a specific alloy. For example, the abrasion resistance of Ni-Hard is higher than that of a quench and tempered low-alloy steel of equal hardness, due to the higher matrix carbon content as well as the presence of carbides of higher individual hardness. In practice, hardness is usually the best and only real means of quality control of white irons.

The carbon content of white irons is limited by the appearance of coarse primary carbides. As long as they are well supported by a resilient matrix, which prevents them from being fractured and torn out by the abrasive, they are beneficial. If this support is not possible, the carbon content should not be raised above the eutectic composition.

The appearance of graphite is highly detrimental to abrasion resistance.

### Resistance to fracture

An important consideration in the selection of abrasion-resistant irons and steels is their resistance to fracture. The toughness of white irons is as difficult to quantify as is resistance to abrasion. The usual methods for measuring toughness in ductile materials—like tensile elongation or notched or unnotched impact resistance—do not apply to the brittle white irons. Results are often meaningless and can be more representative of testing conditions and operator

skill than of the material properties. It should be noted that most testing is done at room temperature. In actual usage the material may be subject to low-temperatures which then adds the effect of the ductile-to-brittle-temperature on the performance. At high operating temperatures, the effect of hot hardness of the matrix metal becomes important.

Generally, a decrease of the carbon (resp. carbide) content and rounded or discontinuous carbides improve the toughness.

White irons with a matrix of tempered martensite have the best overall fracture resistance. White irons containing higher amounts of austenite can appear quite tough in single impact or bending conditions but can fail due to spalling or fracture under repeated loading. The reason is a strain-induced martensitic transformation resulting in high internal stresses. Irons containing bainite, where the bainite is an extremely fine-grained mixture of ferrite and high carbon austenite, behave like irons with an austenitic matrix. Pearlitic white irons have a comparatively low toughness.

Again, it should be emphasised that hardness bears no direct relationship to toughness but is a useful indicator of the likely structure.

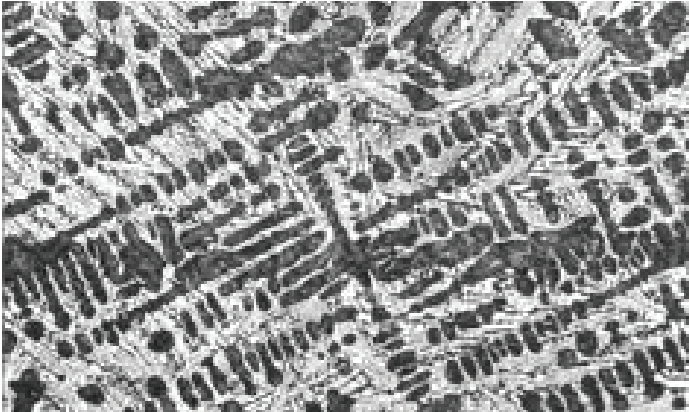
The practical meaning of toughness for an abrasion-resistant white iron is survival without breaking during service. The

---

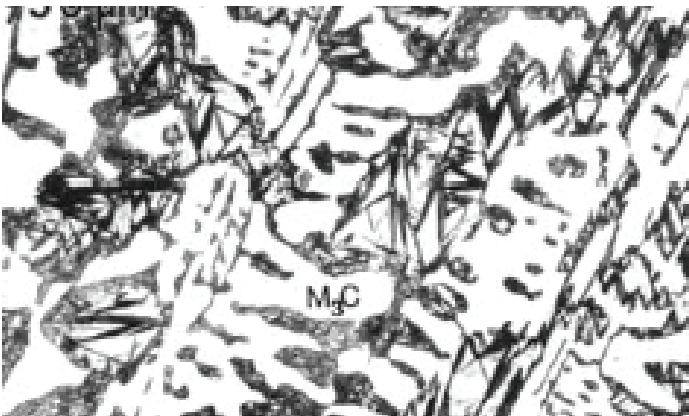
### Ni-Hard liners installed in a pump box



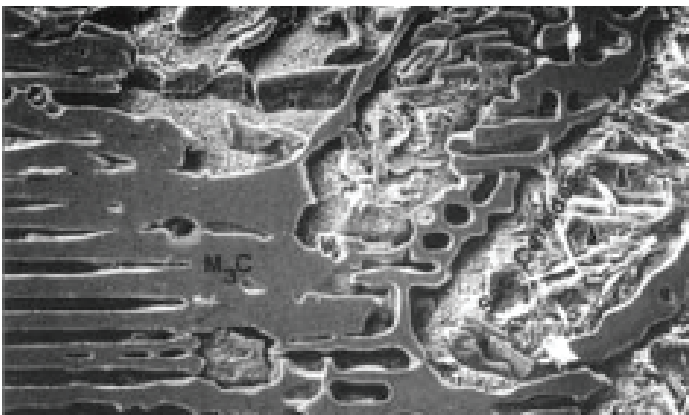
Figure 4 Microstructure of Ni-Hard 1 in the as-cast condition.



Primary dendrites and eutectic.



Optical micrograph. The eutectic M<sub>3</sub>C carbide morphology consists of continuous plates. Within the matrix, the dark acicular streaks are martensite and the lighter areas are austenite. Etched with Vilella's.



SEM micrograph of a deep-etched Ni-Hard 1 sample, showing the continuous plates of the eutectic carbide and secondary carbides within the matrix. Etched with Aqua Regia.<sup>15</sup>

Figure 5 Effect of carbon content on hardness of Ni-Hard 1 in the as-cast condition at various silicon levels<sup>7</sup>.

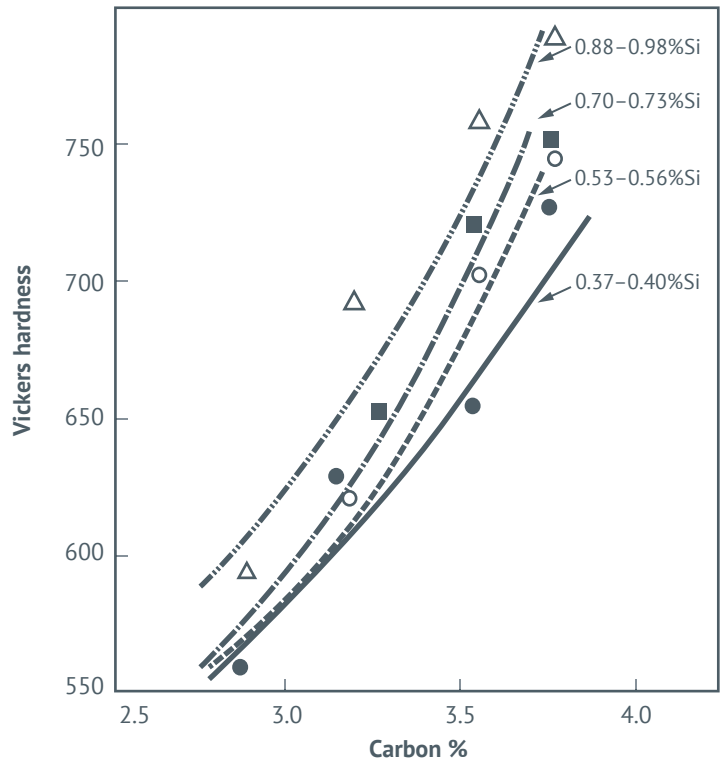
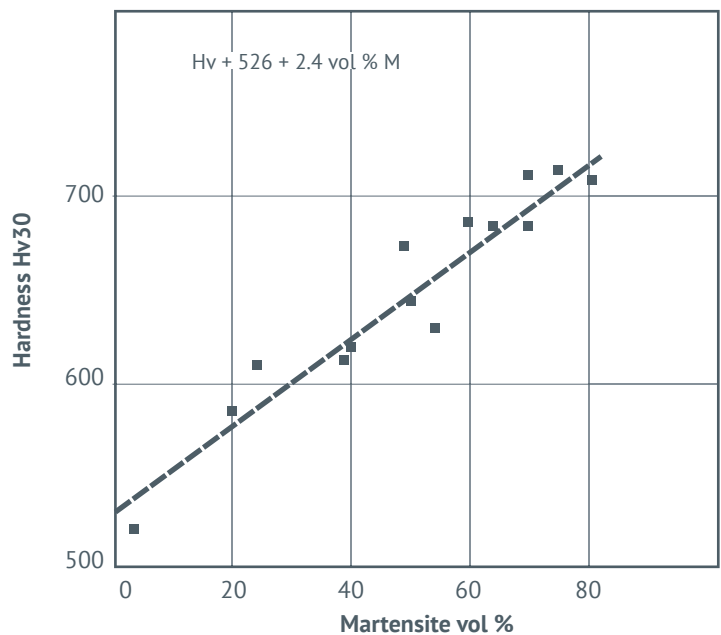


Figure 6 Effect of matrix martensite content on the hardness of Ni-Hard 2 casting tempered at 270°C (525°F)<sup>2</sup>





conditions resulting in fracture can be single or repeated impact, or static or dynamic bending stresses. Here the inherent low ductility of the iron is often overridden by the presence of internal stresses due to shape and heat treatment of the casting and any casting defects. The integrity of the castings and the care and control used in heat treatment are decisive factors in service performance.

The toughness and ductility of the Ni-Hard series is superior to that of the high chromium white irons simply because the matrix metal contains a significant amount of nickel which greatly adds to the overall toughness.

## NI-HARD GRADES AND COMPOSITIONS

Ni-Hard has a microstructure consisting of carbides and a martensitic-austenitic-bainitic or predominantly martensitic matrix. This is achieved by a balanced composition of carbon, nickel, chromium, silicon and final heat treatment.

### Standard Ni-Hard 1 and 2

Ni-Hard 1 and 2 are essentially 4% Ni, 2% Cr irons, their compositions are shown in *Table 1*.

### Microstructure

The microstructure of Ni-Hard 1 and 2 consists of primary dendrites and the carbide eutectic; the eutectic is a mixture of  $M_3C$  carbide plates and matrix (*Figure 4*).

The hardness of Ni-Hard 1 is a function of its carbide content and matrix structure. The effect of carbon is shown in *Figure 5*.

After solidification the austenite is transformed to martensite, some bainite, retained austenite, and secondary carbides. The final matrix will depend on the alloy balance, rate of cooling after casting, and an eventual heat treatment. The hardness of a casting with a given carbon content is directly related to the martensite content of its matrix, as demonstrated by *Figure 6*. For maximum hardness and abrasion resistance, the as-cast martensite content should be as high as possible.

### Carbon

The carbon content determines both the relative amounts of carbides and matrix and the hardness for a given matrix structure (*Figure 5*). Ni-Hard 1 contains about 40 to 44 vol.% of eutectic carbide of the  $M_3C$  type, Ni-Hard 2 about 35 to 40 vol.%. This is the main difference between Ni-Hard 1 and 2.

The lower carbon content of Ni-Hard 2 gives more primary dendrites at the expense of the carbide content. This results in a lower hardness and abrasion resistance but a higher toughness. By changing the carbon content within the limits shown in *Table 1*, abrasion resistance and fracture resistance can be adjusted according to the requirements of the application.

### Nickel

The nickel content is essential in order to obtain a martensitic-bainitic matrix structure without pearlite. The necessary nickel content depends on the casting section

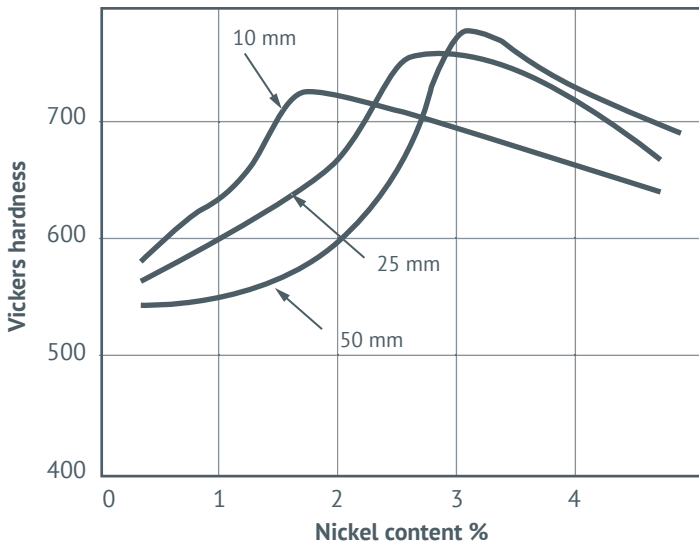
**Table 1** Compositions of the Ni-Hard irons

Grade		Chemical composition* (weight %)							
		C	Ni	Cr	Si	Mn	Mo	S	P
	<b>ASTM A532</b>								
Ni-Hard 1	Class 1, Type A	2.8-3.6	3.3-5.0	1.4-4.0	0.8	2.0	1.0	0.15	0.3
Ni-Hard 2	Class 1, Type B	2.4-3.0	3.3-5.0	1.4-4.0	0.8	2.0	1.0	0.15	0.3
Ni-Hard 4	Class 1, Type D	2.5-3.6	4.5-7.0	7.0-11.0	2.0	2.0	1.5	0.15	0.10
	<b>EN 12513</b>								
Ni-Hard 1	EN-JN2039	3.0-3.5	3.0-5.5	1.5-3.0	0.8	0.8	-	0.10	0.10
Ni-Hard 2	EN-JN2029	2.5-3.0	3.0-5.5	1.5-3.0	0.8	0.8	-	0.10	0.10
Ni-Hard 4	EN-JN2049	2.5-3.5	4.5-6.5	8.0-10.0	1.5-2.5	0.3-0.8	-	0.08	0.08

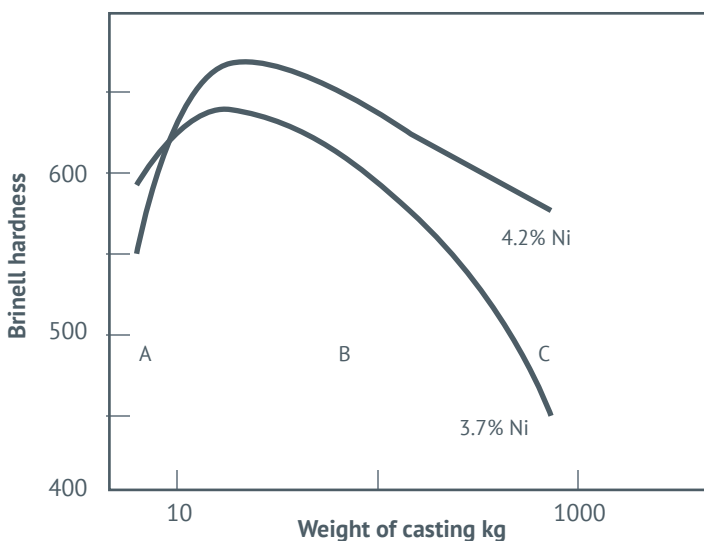
\* Single values are maximums

and the cooling rate, as indicated in *Figures 7 and 8*. The hardness maximum providing best abrasion resistance corresponds to the nickel content producing the maximum

**Figure 7** Hardness of as-cast Ni-Hard 1 in various sections as a function of the nickel content<sup>8</sup>



**Figure 8** Effect of nickel on the as-cast hardness of Ni-Hard 1. Zone A is a region where a lower nickel content should be used in order to avoid excessive austenite formation. In zone B the 4.2% Ni irons have a satisfactory matrix, whilst 3.7% Ni irons fall away in hardness as significant amounts of pearlite or bainite appear. In zone C alloying with 3.7% Ni is quite inadequate and whilst 4.2% Ni irons maintain good hardness levels, higher nickel contents are necessary for the best results.<sup>9</sup>



amount of martensite in each section. At lower nickel contents, hardenability is not enough to suppress pearlite formation, resulting in reduced hardness and abrasion resistance. An excessive nickel content will favour the formation of retained austenite, which will lower the hardness. Abrasion resistance may be good in certain applications but there is a risk of increased spalling and fracture under repeated dynamic stresses. *Table 2* shows the usual nickel and chromium contents of Ni-Hard 1 and 2 for various sections cast in sand or permanent molds.

For each section, the optimum nickel content is slightly higher for a lower carbon content. Most of the nickel is concentrated in the matrix; the higher matrix share in the structure of lower carbon irons reduces its nickel concentration.

### Chromium

Chromium serves to compensate for the graphitising effect of nickel, thus giving a completely white microstructure without graphite. The chromium-nickel ratio is usually kept at between 1:2 and 1:2.5 (*Table 2*). *Figure 9* shows typical graphite precipitates. They appear in the zones between the eutectic carbides which are richer in silicon and nickel and lower in chromium due to segregation. Since free graphite reduces abrasion resistance, it should be avoided except for special applications such as metal working rolls.

Chromium is mainly concentrated in the carbide phase and increases its hardness. Chromium contents above the values

**Table 2** Nickel and chromium contents of Ni-Hard 1 and 2 as a function of section (Guideline values)

Section mm	Ni-Hard 1				Ni-Hard 2			
	Sandcast		Chill-cast		Sandcast		Chill-cast	
	Ni	Cr	Ni	Cr	Ni	Cr	Ni	Cr
<12	3.8	1.6	3.3	1.5	4.0	1.5	3.5	1.4
12-25	4.0	1.8	3.6	1.7	4.2	1.7	3.8	1.5
25-50	4.2	2.0	3.9	1.9	4.4	1.8	4.1	1.6
50-75	4.4	2.2	4.2	2.1	4.6	2.0	4.4	1.8
75-100	4.6	2.4	4.5	2.3	4.8	2.2	4.7	2.0
>100	4.8	2.6	4.8	2.5	5.0	2.4	5.0	2.2

indicated in *Table 2* are normally not recommended because excessive chromium favours the formation of retained austenite.

**Silicon**

Silicon is a graphitiser and should be kept at a low level in order to avoid the formation of graphite, which reduces abrasion resistance. However, enough silicon is necessary to avoid casting defects. Thus, there is a balance in silicon content necessary to optimise abrasion resistance but minimise casting defects. Also, the matrix will contain a coarse acicular phase which reduces impact fatigue. Special grades of Ni-Hard can be produced with higher silicon contents (see section on Special Ni-Hard 1 and 2).

**Manganese**

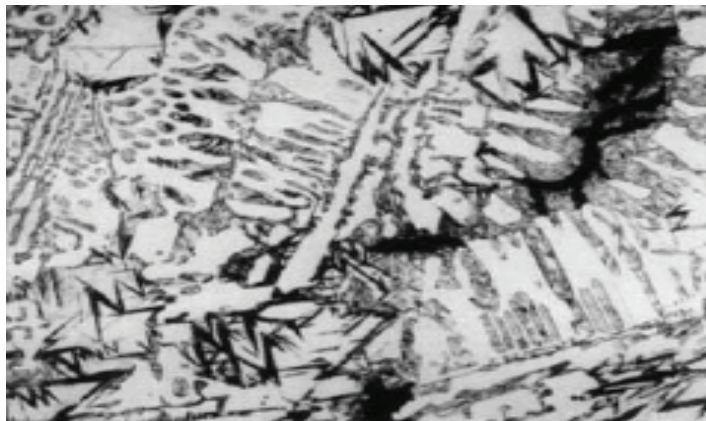
A manganese content of about 0.5 % is advisable. Manganese increases hardenability and complements nickel in this respect. However, its power to suppress pearlite formation is much lower than its effect on austenite stabilisation.

Note: Attempts to maintain hardenability by increasing the manganese content at the expense of nickel have resulted in an iron where the structure's hardness can vary widely between different sections due to segregation.

**Molybdenum**

Small amounts of molybdenum are sometimes added to heavy section castings to increase their hardenability. Since part of the molybdenum is contained in the carbide phase, it cannot be used to replace nickel.

Figure 9 Graphite precipitates in the centre of a 50 mm plate section of Ni-Hard 1 with an unbalanced silicon content of 1.3%.



**Copper**

Copper increases hardenability and is sometimes used to replace part of the nickel. But its effect is only half as strong as nickel<sup>10,11</sup> and decreases as the copper content increases. Copper also has a limited solubility in low nickel cast iron. Further, small copper contents in the range of 0.25 to 0.5 % may embrittle the iron due to the formation of needle-like precipitates resulting from a possible interaction with oxygen.

**Sulfur and phosphorus**

Both elements reduce the toughness of Ni-Hard and should therefore be kept to the lowest level practicable. Sulfur is also known to decrease the abrasion resistance of white irons.

**Magnesium**

A magnesium addition to give 0.02 to 0.05 % residual magnesium will increase as-cast hardness due to a higher martensite formation; it also makes the carbides more discontinuous, improving toughness.

**Special Ni-Hard 1 and 2**

The base composition of standard Ni-Hard has been modified in some instances to give grades with improved properties or special-purpose grades.

**Wear segments for Clinker Grinder**



PITTSBURGH FOUNDRY, PITTSBURGH, PA, U.S.A.

### Higher silicon content

The transformation of austenite to martensite is favoured by a higher silicon content. Increasing the silicon content to about 1.5% results, therefore, in a harder matrix with less retained austenite and more martensite, reaching a hardness level of above 700HB. The graphitising effect of silicon must be compensated by an increased chromium level and a ladle addition of about 0.015% bismuth. The recommended Cr-Si ratio is 2.5:1 for light sections and 2.9:1 for heavy sections. Silicon also reduces hardenability, such that the nickel content must be increased by a factor of  $1.3 \times \%Si$ .

This type of Ni-Hard 1 is known under the trade name of Premium Ni-Hardz.

### Boron

Ni-Hard 1 containing 0.25 to 1.0% boron is extremely hard and abrasion resistant but also very brittle. Its chromium content of about 2.4 to 2.7% is higher than normal Ni-Hard. Boron dramatically increases the hardness of the matrix such that the bulk hardness of this alloy can reach 1,000 DPH after chill-casting. Due to its brittleness, this type of Ni-Hard can be used only for parts that do not undergo impact loading. It can also be used for hard surfacing.

### Graphite

If the silicon content is not balanced by an adequate amount of chromium for a given section, graphite will be precipitated. Uncontrolled graphite precipitates, as shown in *Figure 8* in the zones between the eutectic carbides, are undesirable because they reduce abrasion resistance.

In rolling mills, where a completely different wear mechanism operates, a controlled graphite content can greatly improve thermal fatigue resistance. Proper melting practice and careful balance of the composition, inoculation, and the effect of the chill mold and its coating in relation to the roll diameter will give the desired surface hardness and hardness profile over the cross section. *Figure 10* shows a typical structure of a so-called “indefinite-chill” roll which is used extensively in hot strip mills.

A magnesium treatment followed by a graphitising inoculation of a Ni-Hard type alloy will provide graphite in the nodular form. Such alloys have a lower abrasion resistance than graphite-free Ni-Hard, but they are reported to exhibit a somewhat better fracture resistance in certain applications.

### Titanium

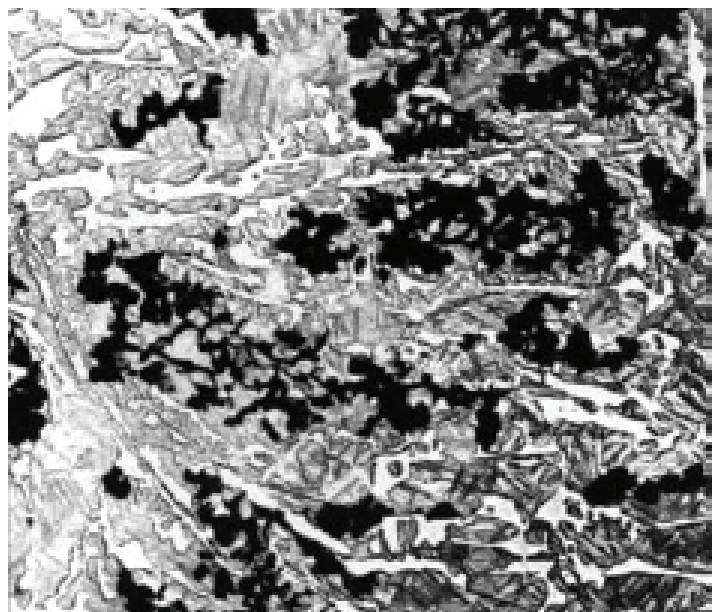
In cast iron, titanium forms titanium carbides (TiC) with an extremely high hardness of about 3,200 HV. They are precipitated from the melt at temperatures of about 1,700 °C (3090 °F) – far above liquidus - and are therefore randomly distributed within the carbides and the matrix.

Such metal-matrix-composites (MMC) of hard particles in a white iron “matrix” have excellent abrasion resistance<sup>12</sup>. Despite their lower specific density, the titanium carbides have little tendency for segregation and do not float to the top of the melt, so that even heavy section castings like pulveriser rolls for coal crushers have been produced successfully. The Ti-C ratio of TiC by weight is 4% Ti:1% C. With an optimum titanium content of 3.5 to 4% and disregarding the small nitrogen content of the melt, the carbon content of Ni-Hard must be raised by about 1% to get the desired MMC-alloy. This proprietary alloy is known as Tinox<sup>13</sup>.

### Vanadium and niobium

An addition of about 1% V or Nb to Ni-Hard 1 gives a structure of fine hard vanadium or niobium carbide particles in a Ni-Hard matrix with improved abrasion resistance<sup>14</sup>.

**Figure 10** Structure of an “Indefinite Chill” roll with graphite stringers about normal to the surface, following the segregation zones parallel to the eutectic. The matrix is predominantly martensitic-bainitic



## Ni-Hard 4

Ni-Hard 4 is a 9Cr-6Ni-2Si white iron designed to give a structure with rod- or blade-like eutectic  $(Cr,Fe)_7C_3$  carbides and a matrix which is free from pearlite in the as-cast condition and predominantly martensitic after heat treatment even in very heavy section castings.

Typical microstructures are shown in *Figure 11*. The desired carbide structure is a result of the combined effect of the balanced chromium, nickel and silicon contents with a eutectic or slightly hypoeutectic carbon content. The carbide volume – 20–28 % – is considerably less than in Ni-Hard 1 or 2.

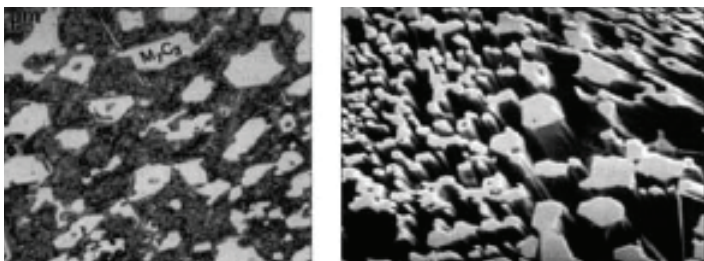
Due to the low carbide volume and the rod-like carbide morphology, Ni-Hard 4 has a higher fracture resistance than Ni-Hard 1 or 2. The as-cast matrix structure consists of about equal amounts of martensite and austenite and some secondary carbides. By a heat treatment, most of the austenite will be transformed to martensite and bainite and more secondary carbides. The retained austenite content will be 10-20%. The composition is shown in *Table 1*.

## Carbon

The carbon content of Ni-Hard 4 gives a eutectic or slightly hypoeutectic composition. The carbon content determines the volume fraction of eutectic carbides which is about 20 % at 2.5 % C and 28 % at 3.5 % C. The effect of carbon content on hardness after heat treatment is shown in *Figure 12*.

The low-carbide volume and the rod-like carbide morphology is the cause of the higher fracture resistance of Ni-Hard 4 compared to Ni-Hard 1 or 2. On the other hand, in applications with low stress abrasion by fine-grained abrasives, where abrasion resistance is determined by carbide volume, Ni-Hard 1 can be more resistant.

**Figure 11** Eutectic microstructures of Ni-Hard 4<sup>15</sup>. Rod-like eutectic carbides are clearly visible (right).



The carbon content is usually kept between 2.9 and 3.2 % as a reasonable compromise between demands for abrasion resistance and toughness.

Fischer<sup>25</sup> has shown that a very good combination of strength, toughness and bend ductility are obtained at relatively high levels of carbon equivalent (CE = 4.03 for 2.1 % Si and about 3.3 % C using formula from Karsay, 26).

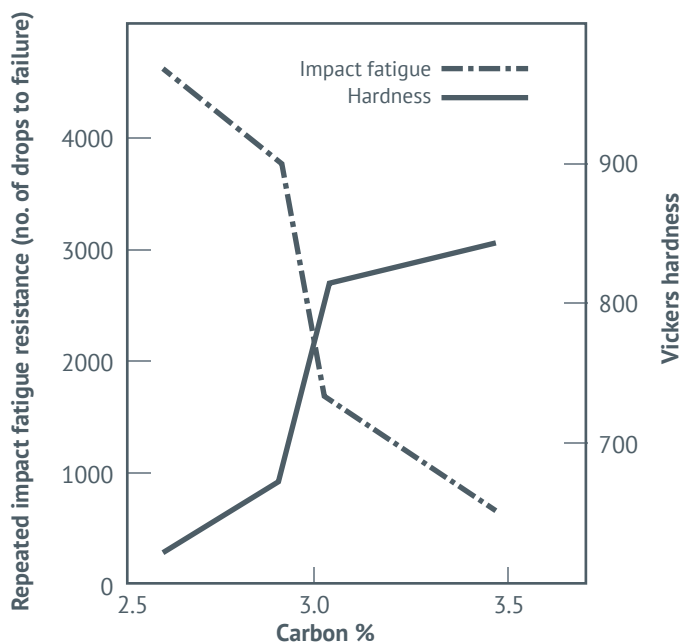
## Chromium

Chromium serves three purposes in Ni-Hard 4. The chromium content of 8 to 10 % is necessary for the desired eutectic  $(Cr,Fe)_7C_3$  carbides instead of the  $(Fe,Cr)_3C$  in Ni-Hard 1 or 2. The effect of silicon on graphite formation has to be compensated by a sufficient amount of chromium. Finally, chromium increases hardenability even if the major part is concentrated in the carbide phase. Increasing the chromium content above 10 % offers no advantage but will make it more difficult to transform the as-cast austenite to martensite.

## Nickel

Nickel is required for hardenability and to assist chromium in the formation of eutectic  $(Cr,Fe)_7C_3$  carbides. The exact nickel content depends primarily on the section and type of

**Figure 12** The effect of carbon content on hardness and impact resistance of heat-treated Ni-Hard 4.



casting, but a minimum of about 5 % Ni should be maintained to avoid pearlite formation during slow cooling in the mold or during heat treatment. Higher nickel contents than 6.5 % will stabilise the austenite too much; if a higher hardenability is thought necessary, an addition of molybdenum is a better solution than a further increase of the nickel content.

### Silicon

The relatively high silicon content (in a white iron) of Ni-Hard 4 is essential in achieving the rod-like  $(Cr,Fe)_7C_3$  carbides. At 9% Cr and 3% C, the necessary silicon content is about 1.7%. Lower silicon contents result in mixed carbide morphologies which may impair toughness and abrasion resistance. The minimum silicon content is lowered by higher chromium and nickel and lower carbon contents and increased in higher carbon compositions. However, raising the silicon content above 2% involves the risk of graphite precipitation in heavy sections, especially if the chromium content is on the low side, and the carbon content on the high side of the range. A target for silicon content of between 1.8 and 2.0% is recommended. The effect of silicon and carbon equivalent on the bend toughness of Ni-Hard 4 is shown in *Figures 13, 14*<sup>25</sup>.

A second effect of silicon is that it favours the transformation of austenite to martensite.

### Manganese

Manganese increases hardenability, but austenite stability even more and should therefore be kept in the recommended range of 0.4 to 0.6%.

### Molybdenum

Molybdenum will improve hardenability without undue stabilisation of the austenite. Thus, 0.5 to 1.5% Mo can be added to increase the hardenability in heavy and very slowly cooled castings. This is preferred to an increase in the nickel content above 6.5%.

### Sulfur and phosphorus

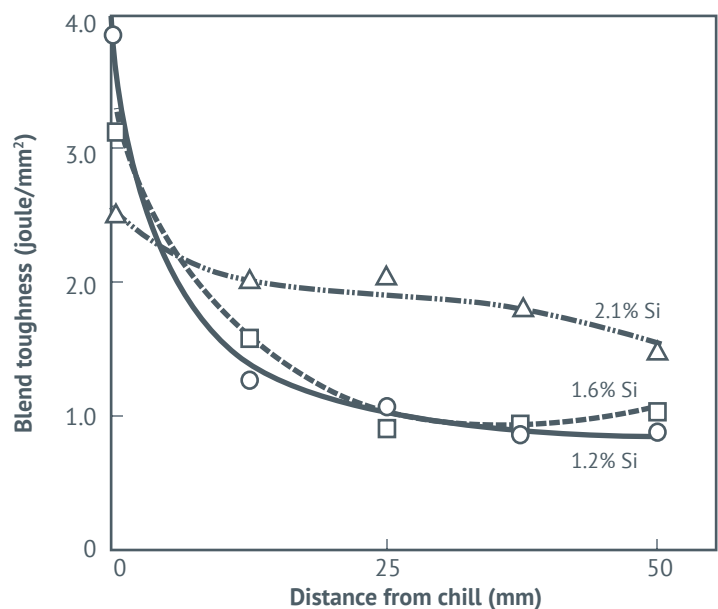
Both elements are detrimental to the toughness of Ni-Hard 4 and should be kept to the lowest level practicable. Sulfur is also known to reduce the abrasion resistance of white irons.

### Graphite

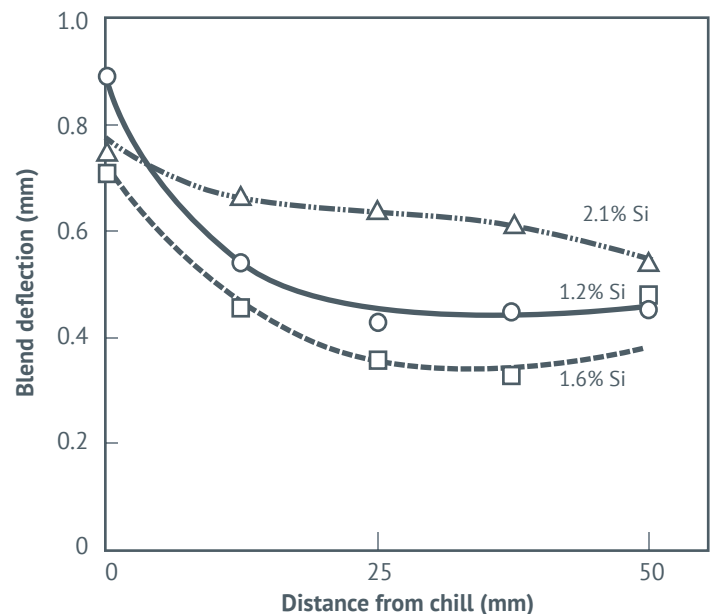
Despite the high chromium content of Ni-Hard 4, graphite precipitation is possible. Thus, an indefinite chill structure like

Ni-Hard 1 can be achieved by increasing the silicon content to above 2.5%, at 3.2 to 3.5% C. At silicon contents above 2.8%, however, the hardness in the as-cast condition cannot be raised by a heat treatment as in normal silicon Ni-Hard 4.

**Figure 13** Bend toughness results as a function of distance from the chill for three levels of silicon (carbon equivalent)<sup>25</sup>



**Figure 14** Bend deflection results as a function of distance from the chill for three levels of silicon (carbon equivalent)<sup>25</sup>



## PRODUCTION

In considering production practice, Ni-Hard should be considered as a high-strength ferrous material. Casting quality and service performance are determined by charge materials, composition and melting practice as well as moulding, internal and external soundness, and surface finish. These must be carefully controlled.

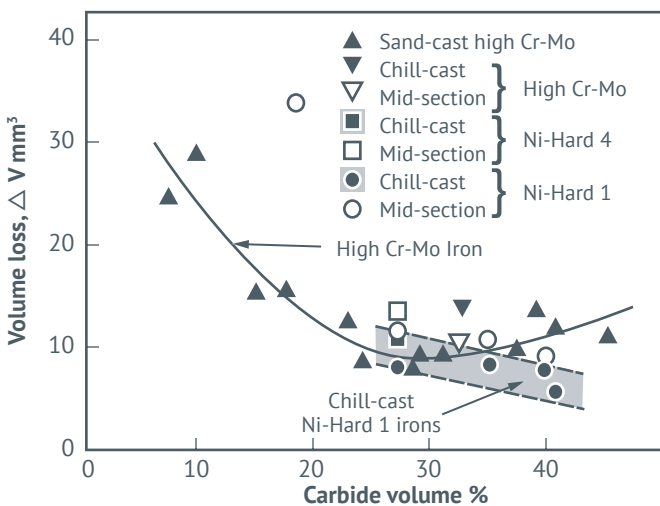
### Molding and methoding

All sands and binder systems used for grey and ductile cast irons or steel castings can be used to make molds and cores for Ni-Hard. Chills and insulating or exothermic riser sleeves can be used similarly as for cast steel in order to improve feeding and casting yields. Breaker cores at riser contact are useful in removing risers. In the use of split chills, it must be recognised that the joint between two chill plates can be a starting point for cracks.

Ni-Hard 1 and 2 castings of simple shape without cores can be produced in chill or permanent molds.

Casting Ni-Hard 1 or 2 against a chill or in chill molds gives a high cooling rate and provides a fine-grained structure. Chill-casting also allows the use of higher carbon and silicon contents without risk of graphite formation, which significantly improves abrasion resistance, as shown in *Figure 15*. This contrasts with high-chromium irons or

**Figure 15** Relation between carbide volume and abrasion resistance determined in the rubber wheel abrasion test with sand and chill-cast Ni-Hard 1 and high chromium irons<sup>14</sup>.



Ni-Hard 4 where chilling does not provide any benefit but seems rather to reduce abrasion resistance.

The beneficial effect of chill on abrasion resistance and mechanical properties of Ni-Hard 1 and 2 is frequently exploited by casting the wear side of the part against a chill plate. But if one side of the casting is cast against a chill, the different cooling rates can cause distortion.

The Ni-Hard cast irons do not contain graphite; thus, their shrinkage behavior at solidification is different from grey iron and similar to steel. The volumetric shrinkage during solidification is 4.5 to 6%.

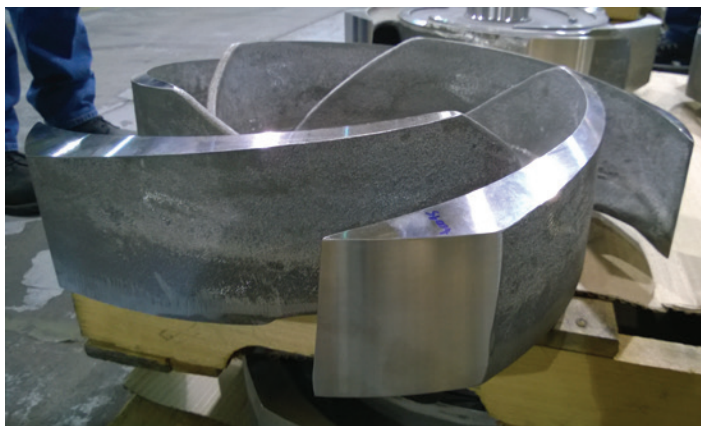
Runners, ingates and risers should be generous and allow a directional solidification. The feeding distance for Ni-Hard is similar to, or somewhat greater than, that found in the casting of steel of similar section thickness and configuration.

The pattern-makers' shrinkage is between 1 and 2% (1 to 2 cm per metre or 1/8 to 1/4 in. per ft.). Typical values for Ni-Hard 1 and 2 are 1.25% for restricted and 1.95% for unrestricted shrinkage.

For Ni-Hard 4, the corresponding shrinkage values are 1.80 and 2.25%.

Shrinkage depends on the amount of retained austenite in the matrix because austenite has a higher shrinkage coefficient than martensite. This results in a peculiarity which must be kept in mind. The casting has an austenitic matrix after solidification and shrinks with a

**Open vane impeller**



Increasing abrasion resistance

factor close to 3% until the transformation of austenite to martensite starts. This is at about 250 °C (482 °F) for Ni-Hard 1 and 100 °C (212 °F) for Ni-Hard 4. This transformation is accompanied by a volume increase such that the shrinkage stops or even turns into an expansion. This means that temperature differences and associated differences in austenite stability can create high stresses. These can either remain as internal stresses or cause the casting to rupture.

Soft and collapsible cores are used to accommodate the high shrinkage, especially for large castings. The cores are sometimes loosened after solidification.

The cooling rate should be as slow as possible, especially in the critical range of martensite formation. Small castings should be allowed to cool slowly in the sand mold to below 50 °C (120 °F). Large castings can be shaken out early and then covered with insulating material to cool slowly almost to ambient.

### Melting

Ni-Hard 1 was originally designed for cupola melting, but today the use of electric melting is almost universal.

Cupola melting Ni-Hard 1 or 2 will not produce high-quality castings. Melting Ni-Hard 4 in a cupola is not recommended because of the excessive carbon pickup of this high-chromium alloy.

Melting Ni-Hard in modern rotary furnaces with oxygen/gas or oxygen/oil burners is possible, but some experience is

needed to control chromium loss. Since carburisation of steel scrap is difficult, low silicon pig iron must be used.

Electric melting, especially in induction furnaces, is the preferred way to produce high-quality Ni-Hard castings. Refractories can be acid, neutral or basic.

The charge materials are steel scrap, white pig iron with low silicon, sulfur, and phosphorus contents, Ni-Hard returns and scrap, and suitable alloy additions. Stainless steel scrap can be used as a nickel and chromium source. Grey or ductile iron scrap can lead to graphite precipitation. The silicon content must be carefully controlled and an eventual silicon pickup from an acid lining must be considered.

The quality of induction melted Ni-Hard depends on careful selection of raw materials with limited use of returns and Ni-Hard scrap to allow room for virgin material in the charge, and a melting practice that produces uniformly low hydrogen and oxygen contents. As the amount of returns and scrap in the charge is increased at the expense of primary materials, some loss in quality is inevitable.

The more returns are used, the higher the oxygen content in the metal. If the ratio of returns and virgin material is kept constant, a constant equilibrium oxygen content will be reached. Oxygen reduces toughness, giving breakage during handling, heat treatment, or in service. It may also be a cause for hot tearing, especially in conjunction with sulfur. Oxygen interacts with residual copper to form embrittling needle-shaped precipitates in the martensitic matrix. The dangerous oxygen content seems to be above 200 ppm, but 600 ppm is not uncommon. Superheating and holding at temperatures of above 1600 °C (2910 °F) should be avoided.

Hydrogen is usually introduced by wet, oily or rusty material charged onto a heel of molten metal in the furnace. A slowly increasing hydrogen level may eventually cause subsurface pinholes in the castings to appear after blast cleaning; later, large blowholes. Hydrogen may also cause cracking in the foundry or erratic breakage of castings in service by a mechanism which seems to be similar to hydrogen embrittlement in high-strength steels. Badly gassed metal in induction melting can be purged by argon introduced via a lance.

Melting should be done as quickly as possible. Melt temperatures should be kept as low as possible in order

### Volute





to avoid excessive oxygen pickup, grain coarsening and deterioration of the carbide morphology.

The tapping temperature is usually 1450-1480 °C (2640-2695 °F).

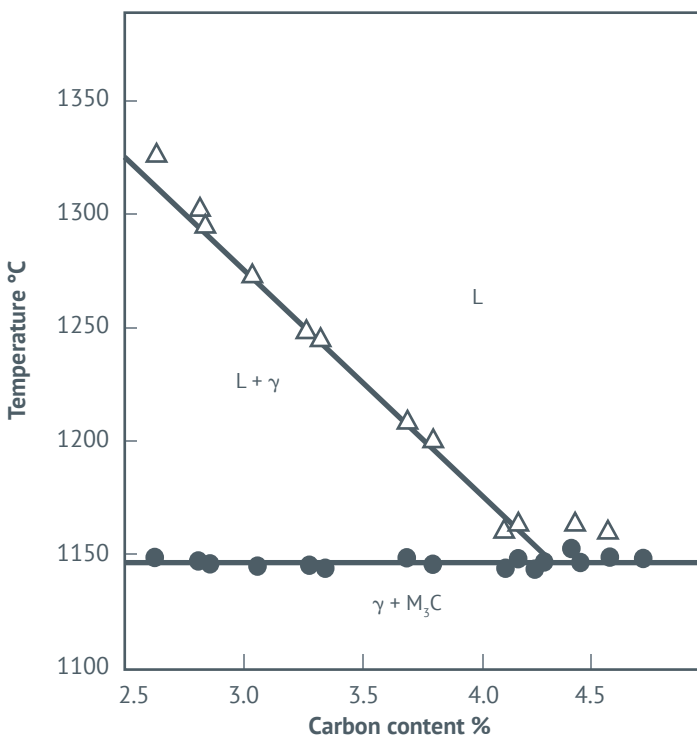
Some producers have found it advantageous for Ni-Hard 1 and 2 melts to be treated with NiMg15 alloy to obtain a residual magnesium content of 0.02 to 0.05 % – additionally, or alternatively, inoculated with 0.15 to 0.20 FeSi75 alloy. These have had a favourable effect on Ni-Hard 1 and 2 in foundry processing and in service because they improve the fracture resistance of the castings.

Little advantage has been found in magnesium treatment or inoculation of Ni-Hard 4. In any case, inoculation cannot improve a poor carbide structure caused by a previous excessive overheating of the melt.

### Casting

The liquidus and solidus temperatures of the Ni-Hard alloys are higher than those of normal cast irons. *Figures 16 and 17*

Figure 16 Partial quasi-binary phase diagrams for Ni-Hard 1 and 2<sup>16</sup>.



show the effect of the carbon content in the partial quasi-binary phase diagrams for Ni-Hard 1, 2 and 4.

Casting temperatures should be kept as low as practicable for good foundry practice and should not exceed 1,450 °C (2640 °F) in order to give a fine-grained carbide structure. The usual range is between 1,350-1,400 °C (2460-2550 °F), depending on the type and section of the casting.

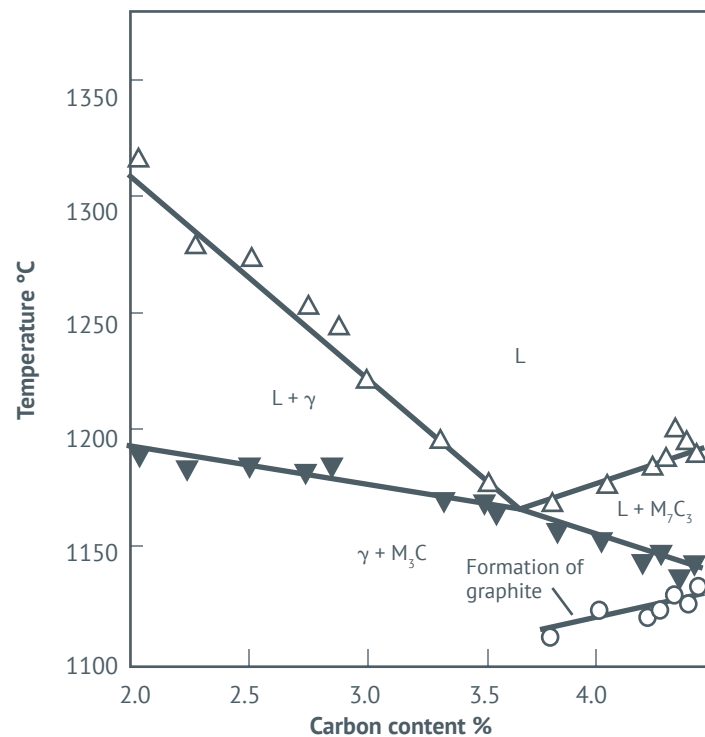
### Bimetallic and compound castings

The idea of combining the high abrasion resistance of Ni-Hard with the toughness and machinability of steel or graphitic cast iron has led to the development of various techniques to produce bimetallic or compound castings.

### Bimetallic castings

Ni-Hard 1 and 2 are especially suited for bimetallic castings because Ni-Hard attains its abrasion resistance in the as-cast condition or after only a low-temperature heat treatment; this avoids problems due to the different transformation behavior and expansion coefficients of the two different materials.

Figure 17 Partial quasi-binary phase diagrams for Ni-Hard 4<sup>16</sup>.



Bimetallic castings are produced by pouring two melts. The problem is to get a good bond at the desired position in the casting without too extensive a mixing of the two materials. This demands a careful control of timing, temperatures, quantity, gating, and pouring velocities. The technique has a long tradition in roll making, where rolling mill rolls consisting of white iron working shell and grey or ductile iron core and journals are common. The vertical cylindrical chill mold with sand molded journals is first filled with Ni-Hard melt. The solidification starts from the chill, moving toward the center of the body. After a specific time only the center and the sand molded journals are still liquid. The second melt is then poured through the same gate at the bottom of mold. Rising in the mold, it pushes the remaining Ni-Hard melt out through the top journal until the core and the journals are filled with softer material.

This deceptively simple technique obviously does not apply to castings of different and more complex shape. Here, more sophisticated methods must be applied to achieve bonding without too much mixing. Sometimes a sheet of steel or nickel serves to separate the two melts for a specific time.

Centrifugal casting is a technique well suited to the production of bimetallic castings. It has been used extensively in roll making and in the production of other castings of symmetrical and cylindrical shape such as various crusher rolls with an outer Ni-Hard working shell, as well as for pipes where the Ni-Hard is on the inside.

---

#### Sand slinger



#### Compound castings

Reinforcing Ni-Hard with cast-in steel bars or rods is simple and efficient. The diameter of the rods is adapted to the section of the casting and they are placed well removed from the working face. The reinforcement extends both longitudinally and laterally in the casting and can take the form of a lattice or spiral arrangement. Care is taken to avoid a metallic bond of the steel rods to the cast metal in order to avoid embrittlement by carburisation of the steel, high stresses due to different expansion coefficients, and defects due to reactions between melt and rust on the steel rod. A refractory coating or a thin sand layer is usual. Clearly the reinforcement cannot rule out cracking of the Ni-Hard under severe dynamic stresses, but it prevents complete breakage and allows the casting to remain in service until it is worn out.

Inserts of mild steel or grey iron are used to allow drilling of holes or thread cutting. Here a metallic bonding is best. Care must be taken to balance insert and casting section to avoid stress cracking. This technique has become less important with the advent of high-performance cutting materials and progress in core making, which allow relatively small holes and even threads to be cast. Low carbon steel inserts are used to allow welding of Ni-Hard castings to other parts of a fabricated assembly.

#### Heat treatment

Ni-Hard was originally intended to be put in service in the as-cast condition. Nowadays, however, almost all castings are heat-treated. There are three basic heat treatments which serve three purposes:

- stress relief and improved toughness, and some improvement of repeated impact fatigue resistance, by tempering at 225-275 °C (437-527 °F) (single-stage tempering)
- improved repeated impact fatigue resistance by a duplex treatment at 450 °C followed by 275 °C (840 °F followed by 495 °F) (double-heat treatment)
- improved hardness and abrasion resistance by soaking at 750-850 °C (1350-1560 °F), slow cooling, and tempering (hardening).

Most Ni-Hard 1 and 2 castings are given the first treatment; the others are used only for special demands. Ni-Hard 4 is always given the third heat treatment.

There are also more intricate heat treatments, and the possibility of a cryogenic treatment of both types of Ni-Hard.

### Ni-Hard 1 and 2

The effects of the two low-temperature heat treatments can be understood by looking at the isothermal transformation diagram in Figure 18.

Single-stage tempering: The single-stage tempering heat treatment at 225-275 °C (437-527 °F) leads to:

- tempering of the martensite and stress relief
- isothermal formation of some bainite
- possibly some slight transformation of retained austenite to martensite.

Tempering of the martensite is the primary rationale. It will improve the resistance of the casting to breakage in service and to crack formation during handling in the foundry – especially during riser removal by grinding. It is often advisable to carry out fettling and finishing operations after stress relief heat treatment.

The effect of this heat treatment on properties can be seen in Figure 19. Tempering of the martensite reduces hardness while repeated impact fatigue resistance increases due to relief of stress. At about 275 °C (527 °F), some retained austenite is transformed to martensite, which improves hardness and especially repeated impact fatigue resistance. Above 275 °C (527 °F), over-tempering can result in bainite formation and a lowering of hardness and impact resistance. The extent of these property changes depends on the relative amounts of austenite and martensite in the matrix. The higher the martensite content, the lower are the two peaks at 275 °C (527 °F) and vice versa. Figure 20 shows the change in hardness resulting from this treatment at different carbon and silicon contents. As described on page 10, silicon increases the as-cast martensite content.

The optimum holding time is 8–16 hours. Longer times will reduce hardness without any further improvement. Cooling can be in still air or in the furnace.

Double-heat treatment: The first stage of the duplex heat treatment involves heating in the range of austenite stability (see Figure 18) for about 4 hours. It is designed to promote

secondary carbide precipitation which reduces the carbon content of austenite. The result is that, on air or furnace cooling the castings to room temperature, more austenite will be transformed to martensite. This will be stress relieved and tempered in the second stage at 275 °C (527 °F). The martensite already present in the as-cast structure will be heavily tempered and lose hardness. Figures 21 and 22 show the change in hardness resulting from the duplex treatment at different carbon and silicon contents. The effect is like the single-stage heat treatment shown in Figure 20.

Figure 18 Typical isothermal transformation diagram of Ni-Hard 1<sup>17</sup>.

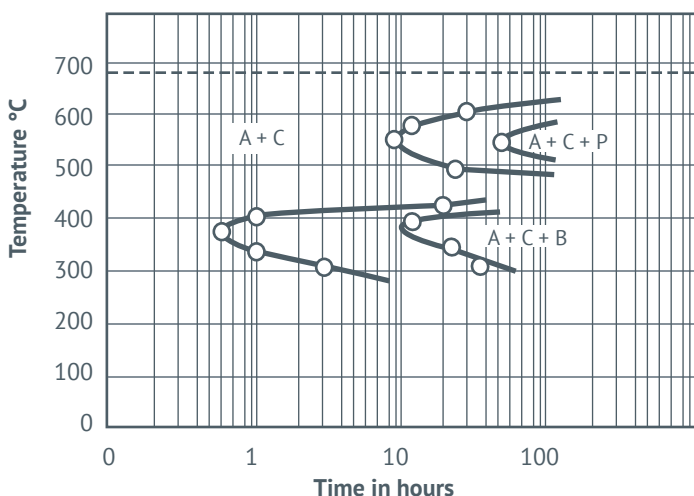
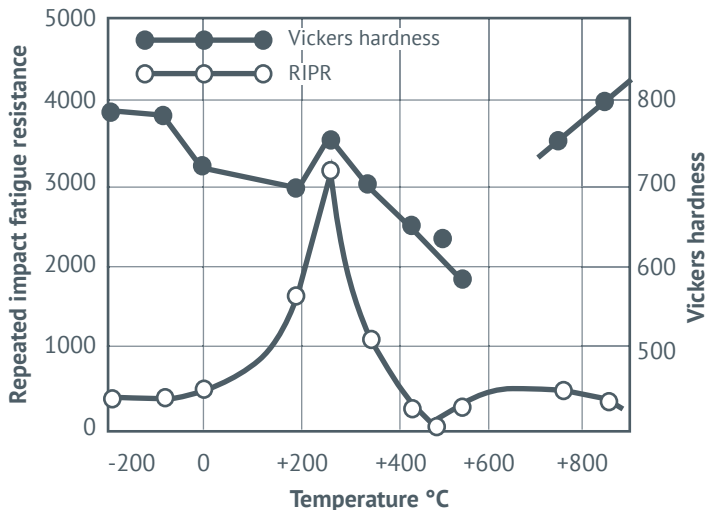
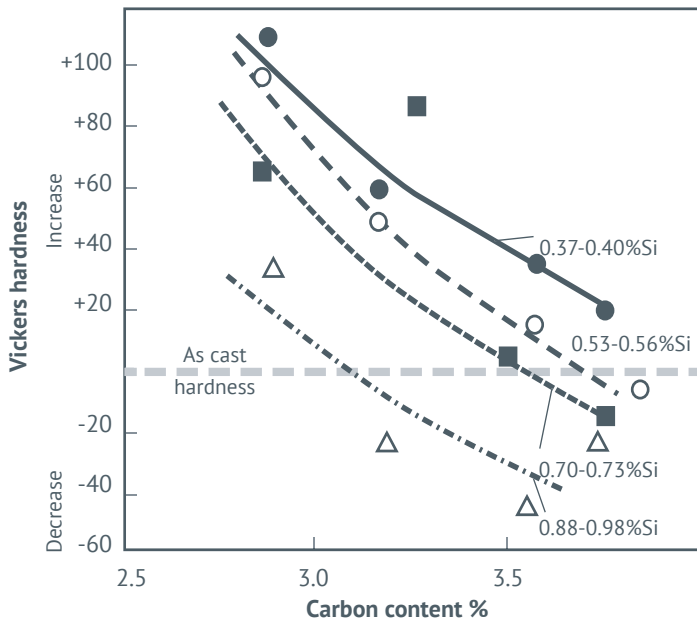


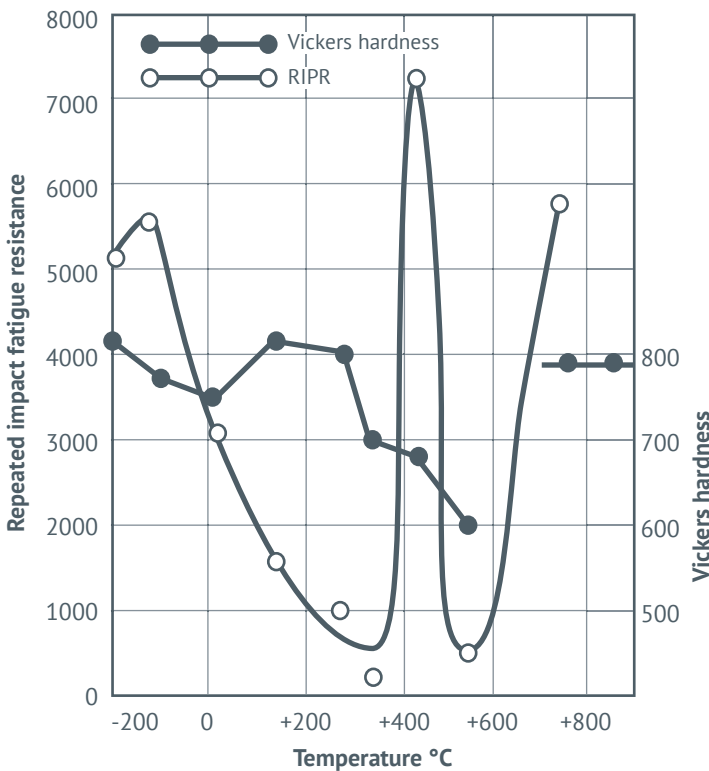
Figure 19 Hardness and repeated impact fatigue of Ni-Hard 1 after tempering at various temperatures<sup>18</sup>.



**Figure 20** Variation of hardness between tempered (285°C, 14 h) and as-cast Ni-Hard 1 irons having different carbon and silicon levels<sup>7</sup>.

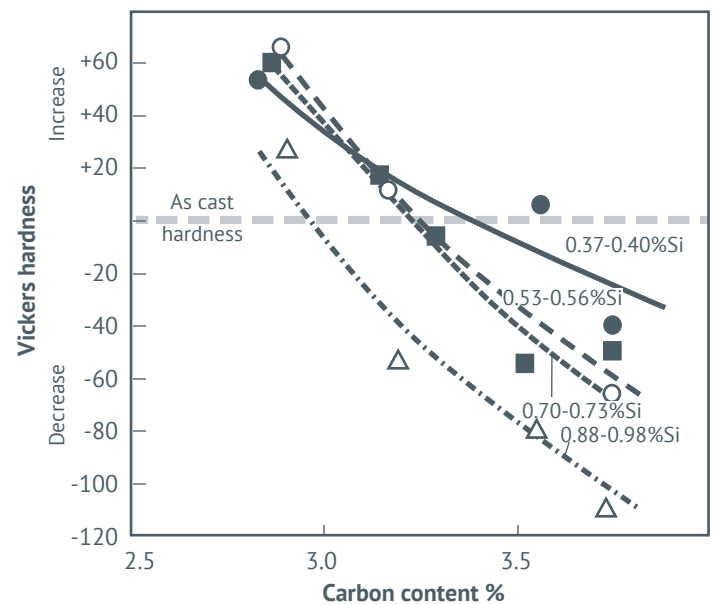


**Figure 21** Hardness and repeated impact fatigue after double heat treatment at 450 + 275°C<sup>18</sup>.

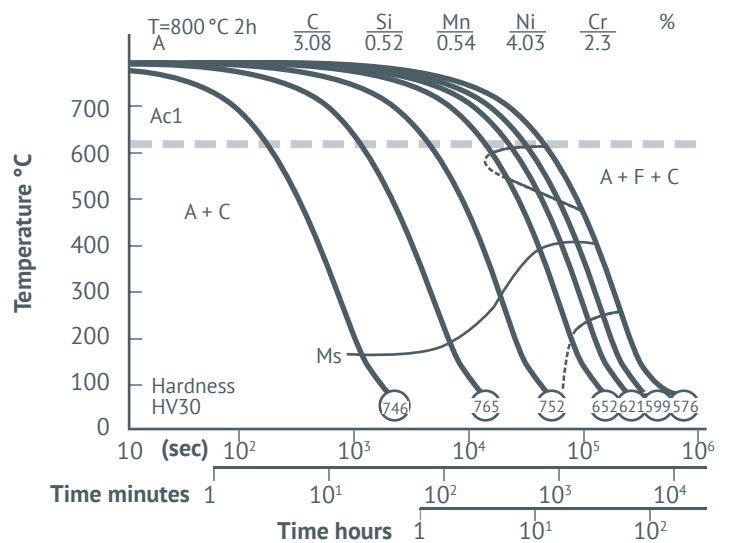


The purpose of this treatment is not to improve abrasion resistance but repeated impact fatigue resistance in castings such as grinding balls and mill liners. It has been argued that a high as-cast martensite content is not essential for castings to be heat treated in this way. In fact, a casting with a higher as-cast austenite content may reach a higher hardness after this heat treatment.

**Figure 22** Variation of hardness between double-heat-treated (460°C, 5 h + 285°C, 14 h) and as-cast Ni-Hard 1 irons having different carbon and silicon levels<sup>7</sup>.



**Figure 23** Continuous cooling transformation diagram of Ni-Hard 1<sup>11</sup>.



**Hardening:** Hardening by high-temperature heat treatment can be followed in the continuous cooling transformation diagram, *Figure 23*. The casting is heated to a temperature in the austenite range. During soaking at this temperature, secondary carbides are precipitated from the austenite which increases the Martensite start (Ms) temperature and facilitates transformation to martensite during cooling to ambient. During slow cooling, more carbides are precipitated such that the Ms temperature increases further, as seen in *Figure 23*. At the same time a certain self-tempering of the martensite results in some loss of that hardness during cooling from Ms to ambient. Maximum hardness is achieved at an intermediate cooling rate determined by the alloy composition of the casting.

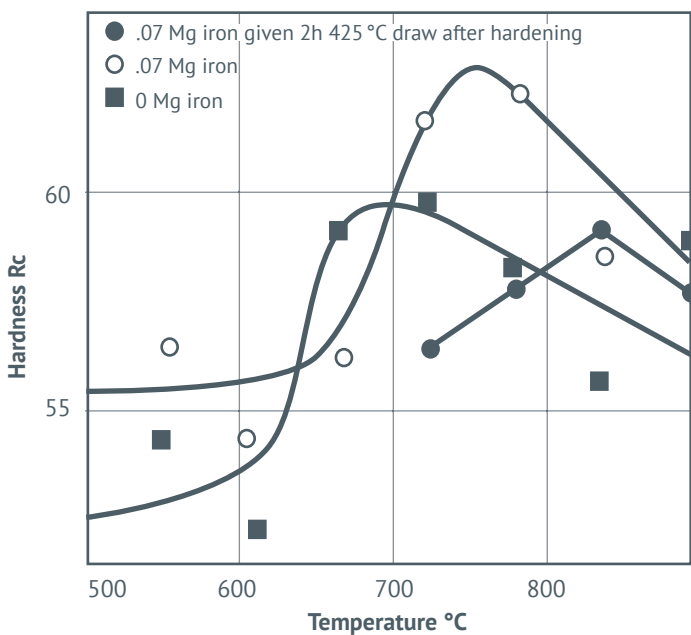
Too high hardenability will result in a high retained austenite content with low hardness, and too little hardenability will produce pearlite and/or bainite of lower hardness. Final hardness after cooling depends also on the hardening temperature, as shown in *Figure 24*. A low hardening temperature will give a lower carbon content in the austenite which lowers the hardness of the resulting martensite and somewhat reduces hardenability. Hardening from high

temperature will stabilise the austenite again due to a higher carbon solubility, and thus decrease hardness.

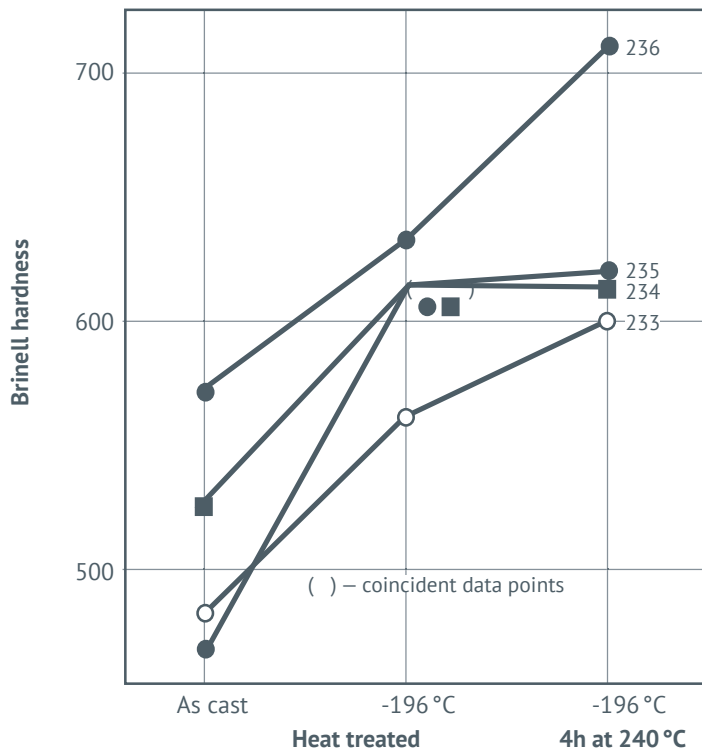
The optimum hardening temperature of Ni-Hard 1 and 2 depends on the alloy composition but is usually a hold for 2 hours at 700–750 °C (1290–1380 °F) followed by cooling in still air or by controlled furnace cooling to avoid cracking.

**Cryogenic treatment:** Cryogenic or sub-zero treatments may also be used to increase the hardness and the abrasion resistance of Ni-Hard 1 and 2 (and Ni-Hard 4 as well). Residual austenite can be transformed at subzero temperatures. Such low temperatures can be reached by using liquid nitrogen. The castings are not immersed or touched by liquid nitrogen but are exposed to the fumes of vaporising liquid nitrogen in an insulated chamber. *Figure 25* shows the

**Figure 24** Effect of hardening temperature on the hardness of Ni-Hard 1 with and without magnesium and effect of 2h tempering at 205°C. Magnesium favours the martensitic transformation<sup>2</sup>.



**Figure 25** Effects of a subzero treatment, a subsequent tempering and magnesium addition on the hardness of Ni-Hard 1<sup>2</sup>.



Average analysis (%) of Ni-Hards used in cryogenic tests

No.	C	Si	Mn	Ni	Cr	Mg	S	P
233	3.09	.55	.50	4.25	2.4	.054	.007	.020
234	3.28	.57	.53	4.20	2.4	.12	.006	.021
235	3.05	.55	.48	3.35	3.40	.036	.011	.018
236	3.26	.56	.53	3.35	3.35	.10	.006	.024

results. Since similar and higher as-cast hardness values can be reached with optimised compositions, such treatment has not achieved commercial significance. This treatment may be considered for hardening complex castings where heat treatment is considered too risky.

#### Ni-Hard 4

As a result of its high alloy content, as-cast Ni-Hard 4 usually contains over 50% retained austenite, giving hardness values which are rarely higher than 550 to 600HV. A more complete austenite transformation to martensite, with a corresponding increase in hardness, is achieved by destabilisation or conditioning of the austenite at temperatures above 750 °C (1380 °F), where austenite stability is lowered by carbide precipitation. *Figure 26* is an isothermal transformation diagram indicating the various transformation ranges. The hardness of samples isothermally held at the various temperatures is listed on the right-hand side.

Industrial heat treatments use destabilisation temperatures of 820–860 °C (1508–1580 °F) with soaking times of up to 10 hours followed by slow controlled cooling in still air or in the furnace. The continuous cooling transformation diagram in *Figure 27* indicates that the highest hardness values result from slow cooling by the precipitation of more secondary carbides at lower temperatures.

The hardenability of Ni-Hard 4 is enough to allow cooling rates up to about 500 °C/hour (900 °F/hour) through the temperature range between 600 °C–300 °C (1110 °F–570 °F) without pearlite formation. Excellent hardness values have also been observed after air cooling to about 600 °C (1110 °F) followed by furnace cool. In complete contrast to steel, Ni-Hard 4 will yield higher hardness at slower cooling rates.

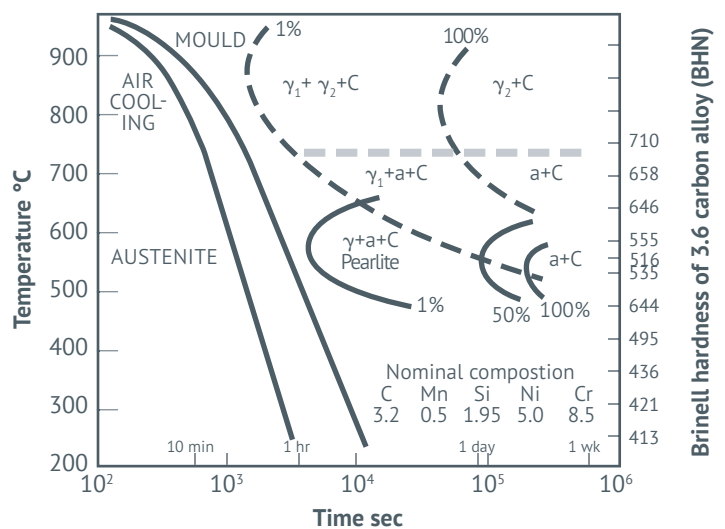
A final tempering at 200–270 °C (392–518 °F) is often used, but the effect on stress relief and fracture resistance is doubtful for slowly cooled castings. The hardness variation is marginal.

Cryogenic treatment of Ni-Hard 4 at -196 °C (-320 °F) in liquid nitrogen will transform as-cast austenite and increase hardness as much or even more than high temperature hardening. The technique is the same as described for Ni-Hard 1. It has been successfully applied in the production of large slurry and dredge pump castings in order to avoid the risk of cracking.

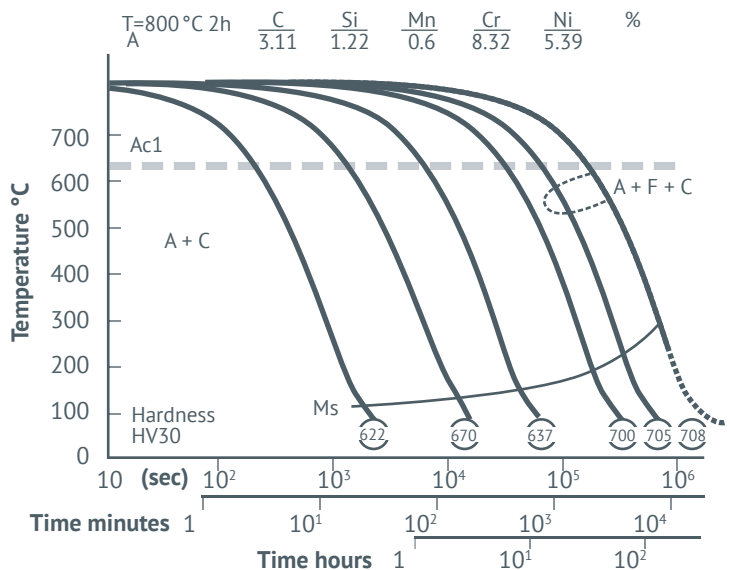
After the cryogenic treatment, the castings should be stress relieved by tempering at 220 °C (428 °F). This may increase hardness even further.

Sub-critical heat treatment: A sub-critical heat treatment of 4 to 8 hours at 550 °C (1020 °F) followed by 16 hours at 450 °C (840 °F) and air cool has sometimes been recommended to improve hardness and repeated impact fatigue resistance of Ni-Hard 4 castings. But the castings may become more brittle<sup>19</sup>.

**Figure 26 Isothermal transformation diagram of Ni-Hard 4.**



**Figure 27 Continuous cooling transformation diagram of Ni-Hard 4<sup>11</sup>.**



This treatment makes some austenite transform to martensite, resulting in an increased hardness, but is far less effective than the high-temperature hardening. It may be considered in order to reduce cost and demand for furnace capacity.

### Finishing the castings

For easy riser removal, breaker cores should be used. But care must be taken to avoid breaking into the body of the casting.

Grinding is best done after heat treatment, to minimise the risk of heat checking and grinding cracks. The temperature generated during grinding must be controlled for the same reason. Comparatively soft grinding wheels are normally used, often of the zirconia-alumina type with medium abrasive grain size.

### Welding

Welding Ni-Hard is not recommended because cracks form in the weldment, the fusion line, and the heat affected zone. In some instances, crack-free or almost crack-free welds have been produced by using high preheat temperatures into the austenite range – i.e., above 700 °C (1290 °F). Even then, welding the surface exposed to abrasion is not recommended because the structure of the weldment will be different from the base material – even when using similar consumables – and this will give uneven wear.

Weld assemblies with Ni-Hard castings can be made by using protruding mild steel inserts.

### SAG Mill Trojan horse liners



### Machining

The high hardness of Ni-Hard makes machining difficult. Due to its lower carbide content, Ni-Hard 2 is easier to machine than Ni-Hard 1.

Grinding is an obvious method of machining Ni-Hard. In order to avoid heat checking, wet grinding is preferred. On modern wet grinding machines, large surfaces of Ni-Hard castings can be machined economically to a close dimensional tolerance.

An essential requirement for machining with cutting tools is to maintain maximum rigidity both in the workpiece and in the cutting tool. Lathes and mills must have heavy head stocks which are robust and in good condition.

Sintered carbide tools can be used, but wear is rapid. Modern ceramic tools, especially cubic boron nitride (CBN) give much better results and allow machining by turning and milling without losing surface finish and accuracy through tool wear. Machining pump casings and rollers for coal mills with CBN is an established practice today<sup>20</sup>. *Table 3* suggests machining conditions for turning Ni-Hard<sup>21</sup>. Typical data for machining 946 mm O/D mud pump casings of Ni-Hard 2 with casting skin on a vertical boring mill with CBN<sup>22</sup> are:

- Speed of the work piece 14 rpm
- Depth of cut 1 to 1.5 mm (0.04-0.06 in.)
- Feed rate during roughing 0.4 mm (0.016 in.)
- Feed rate during finishing 0.25 mm (0.01 in.)

The risk of breaking the expensive Cubic Boron Nitride (CBN) inserts at defects in casting surfaces is often thought to be too high. In such cases the much less expensive and tougher silicon nitride (Sialon) tools can be used despite their lower wear life.

**Table 3 Suggested machining conditions for turning of Ni-Hard with 570-750 HBN with CBN<sup>21</sup>**

Machining operation	Surface speed m/min (sfm)	Maximum depth of cut mm (in)	Feed rate mm/rev (in/rev)
Finishing	40 to 80 (130–260)	1.3 (0.05)	0.05 to 0.15 (0.002–0.006)
Light roughing	40 to 80 (130–260)	2.0 (0.08)	0.05 to 0.20 (0.002–0.008)
Rough turning	40 to 80 (130–260)	3.2 (0.12)	0.05 to 0.40 (0.002–0.016)

Drilling holes and tapping is also possible with CBN provided the diameter is large enough. For small holes, cast-in mild steel inserts are often used. The inserts must be clean and dry in order to avoid defects by reaction with the melt. The inserts must also be located far enough away from the wearing surface for them not to be exposed after some time in service.

In many cases holes and even threads can be cast in using very accurate cores. In such precast holes, steel inserts, which will be tapped, can be screwed in. Care must be taken to avoid bursting a too thin remaining Ni-Hard section while screwing in the insert.

## MECHANICAL AND PHYSICAL PROPERTIES

The typical range of mechanical and physical properties of Ni-Hard are shown in *Tables 4, 5* and *6*. The temperature dependence of some mechanical properties of Ni-Hard 1 and Ni-Hard 4 are shown in *Figure 26* and *Tables 7* and *8*.

## TESTING

The most significant property of Ni-Hard castings is their hardness – and hardness is usually the only property that is determined in practice. The determination of other

properties usually asked for in steels or grey irons – like tensile or bending strength – is difficult and costly. Even the manufacture of suitable test samples from the hard and brittle irons is difficult. The results have little bearing on the service performance of the casting. These facts are also recognised in all standards where other properties than hardness are not specified.

### Hardness

For hardness testing, the scientifically correct and the most accurate method is the determination of Vickers hardness DPH100 or DPH50. This method is, however, not very practicable on the shop floor; in practice the hardness of Ni-Hard castings is indicated as Vickers, Brinell or Rockwell C hardness. This becomes even more complex due to the widespread use of non-standard, but easy-to-use portable hardness testers, the readings of which must be converted into one of the standard hardness scales.

It must be emphasised that the conversion tables or curves for steels or for graphitic cast irons do not apply to Ni-Hard. ASTM A532 contains special conversion tables and formulas for the hardness values of white irons. It should be recognised that these formulas have been obtained by regression analysis<sup>23</sup> and that there is no exact linear relationship between the three scales. It is recommended that supplier and client agree beforehand on the hardness testing method, or at least on the conversion table.

**Table 4 Typical range of mechanical properties of Ni-Hard 1 and 2** <sup>8,14</sup>

Type	Brinell	Hardness Vickers	Rockwell C	Tensile strength MPa (ksi)	Transverse strength* MPa (ksi)	Deflection* mm (in.)	Modulus of elasticity GPa ksi x 10 <sup>3</sup>	Impact** energy J (ft-lb)	Fracture toughness (MN/m) <sup>3/2</sup>
<b>Ni-Hard 1</b>									
Sand cast	550–690	640–750	56–63	280–350 (40–50)	500–620 (72–90)	2.0–2.8 (0.08–0.11)	169–183 (24.5–26.5)	28–41 (20–30)	15–26
Chill-cast	600–730	700–860	58–65	350–420 (50–60)	560–850 (81–123)	2.0–3.0 (0.08–0.12)	169–183 (24.5–26.5)	35–55 (25–40)	–
<b>Ni-Hard 2</b>									
Sand cast	530–630	630–740	54–60	320–390 (46–56)	560–680 (81–98)	2.5–3.0 (0.1–0.12)	169–183 (24.5–26.5)	35–48 (25–35)	–
Chill-cast	580–680	680–800	57–62	420–530 (60–76)	680–870 (81–126)	2.5–3.0 (0.1–0.12)	169–183 (24.5–26.5)	48–76 (35–56)	–

\* 30 mm dia, 300 mm span

\*\* Izod Test, unnotched 30 mm bar, struck 76 mm above support



## Impact fatigue resistance

The resistance to repeated impact is an interesting property for some applications like grinding balls and ball or rod mill liners. This has been extensively covered in technical

literature<sup>18,24</sup>. The testing is done using a non-standardised drop-ball test machine, where balls repeatedly drop from a certain height (usually around 6 meters) onto an inclined anvil until they fail due to spalling or breakage. The average number of drops to failure is used as an indication of the impact fatigue resistance. The absolute number of drops to failure is as much a function of the design of the specific testing equipment and the surface quality of the balls as the composition, heat treatment and microstructure of the alloy. This testing method gives only a ranking of various materials. Generally, it has been found that higher retained austenite contents reduce impact fatigue resistance.

**Table 5 Some typical physical properties of Ni-Hard 1 and 2<sup>8</sup>**

<b>Specific density g/cm<sup>3</sup> (lb/in<sup>3</sup>)</b>	7.6–7.8 (0.274–0.282)
<b>Thermal conductivity – W/m/K (BTU/ft/hr/F)</b>	
at 20°C (70°F)	14–15 (8.1–8.7)
at 120°C (250°F)	14.2 (8.2)
at 450°C (840°F)	18.8 (10.9)
<b>Between</b>	
10–95°C	8–9 (4.6–5.2)
10–260°C	11.3–11.9 (6.5–6.9)
10–425°C	12.2–12.8 (7.0–7.4)

**Table 6 Typical mechanical and physical properties of Ni-Hard 4<sup>8,14</sup>**

Hardness	
Brinell	550–700
Vickers	650–820
Rockwell C	56–63
Tensile strength, MPa (ksi)	500–600 (72–87)
Transverse strength, MPa (ksi)	600–800 (87–116)
Deflection, mm (in.)	2.0–2.8 (0.08–0.11)
Compressive strength, MPa (ksi)	280–310 (40–45)
Modulus of elasticity, GPa (ksi x 10 <sup>3</sup> )	190–200 (27–29)
Fracture toughness, MN/m <sup>3/2</sup>	19–30
Specific density, g/cm <sup>3</sup> (lb/in <sup>3</sup> )	7.75 (0.280)
Thermal conductivity, W/mK (Btu/ft <sup>2</sup> /in./hr/°F)	12.6–15 (87–109)
Specific heat at 20 °C, J/kgK (Btu/lb/F)	500 (0.12)
Specific electrical resistance at 20 °C μΩ-cm (Ω-circ mil/ft)	85 (511)
Mean coefficient of linear thermal expansion μm/m/K (μin/in/F)	
20 to 100°C	14.8 (8.2)
20 to 200°C	15.2 (8.4)
20 to 300°C	15.8 (8.8)
20 to 400°C	15.9 (8.8)
20 to 500°C	15.3 (8.5)

**Table 7 Hot-hardness testing of a heavy section Ni-Hard 1 casting<sup>14</sup>**

Temperature °C (°F)	Hardness HV10
205 (400)	606
315 (600)	521
425 (800)	485
480 (900)	416
540 (1000)	308
595 (1100)	201
650 (1200)	138
760 (1400)	92
815 (1500)	75

**Table 8 Elastic Modulus of Ni-Hard 4<sup>8</sup>**

Temperature °C (°F)	Elastic modulus GPa (ksi x 10 <sup>3</sup> )
20 (68)	196 (28.4)
100 (212)	192 (27.8)
200 (390)	185 (26.8)
300 (570)	178 (25.8)
400 (750)	173 (25.1)
500 (930)	170 (24.6)
600 (1110)	162 (23.5)
700 (1300)	144 (20.9)
800 (1470)	130 (18.8)

### Soundness

Castings are usually checked for surface cracks by the dye penetrant method. Eddy current or Magna Flux can also be used but retained austenite may give wrong indications. The soundness of the castings can be determined by means of the usual ultrasonic or X-ray methods.

### Standards

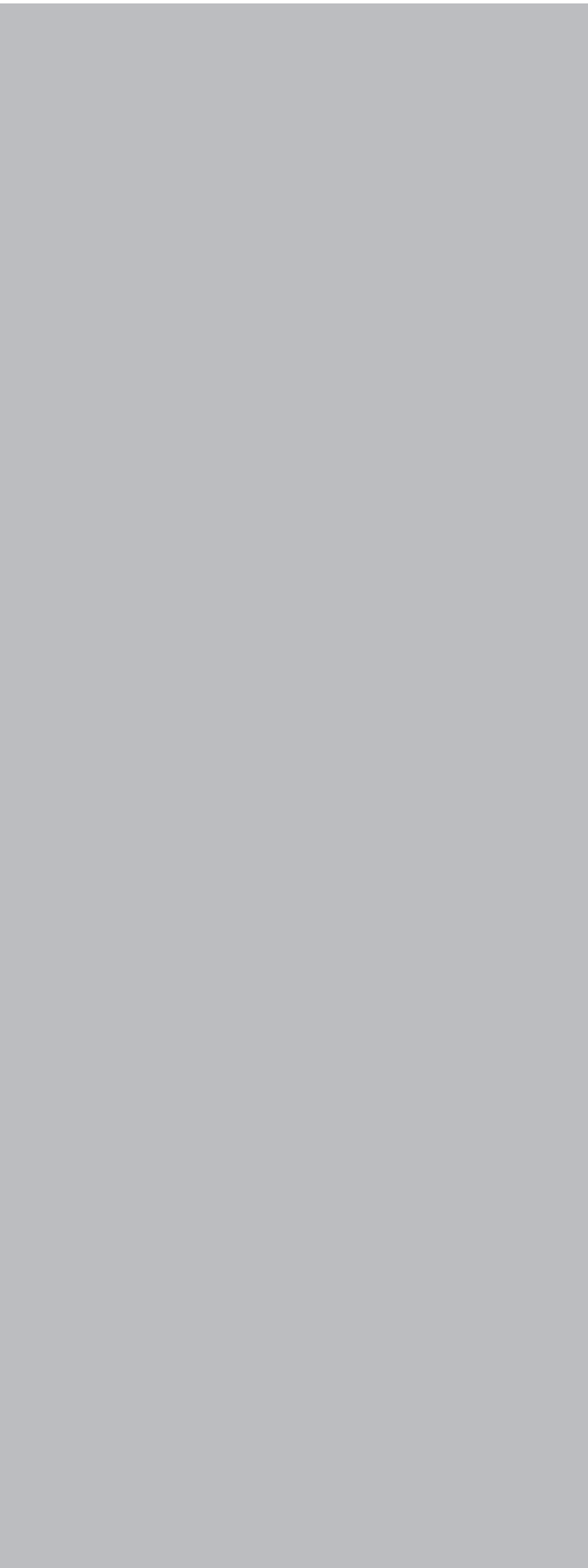
Ni-Hard 1, 2 and 4 are contained in a European Standard and in many national standards under various designations with almost identical compositions. *Table 9* indicates the various standard designations for these three alloys.

Table 9 International standard designations of nearest equivalent grades					
International	US: ASTM A532	EU: EN 12513		India: IS 4771	China: GB/T 8263
		designation	number		
Ni-Hard Type 1	Class 1, Type A	EN-GJN-HV550	EN-JN2039	Type 1a NiL Cr 34/550	BTMNi4Cr2-DT
Ni-Hard Type 2	Class 1, Type B	EN-GJN-HV520	EN-JN2029	Type 1a NiL Cr 30/500	BTMNi4Cr2-GT
Ni-Hard Type 4	Class 1, Type D	EN-GJN-HV600	EN-JN2049	Type 1b NiHCr	BTMCr9Ni5

## BIBLIOGRAPHY

- 1 R.C.D.Richardson, *Wear* 11 (1968), p.245.
- 2 G.J.Cox, Development of Abrasion- resistant, Nickel-containing Alloy White Irons of High Hardness. *Trans. Amer. Foundry Soc.* 97 (1989), p.361-372. (Available from Nickel Institute as Publication No. 10 038)
- 3 Verschleiss durch sandhaltiges Wasser in hydraulischen Anlagen. *Schweizer Archiv* 24 (1958), p.218-230, 248-263.
- 4 K.Röhrig, Abrasionsbeständige Eisengusswerkstoffe. *VDI-Z* 124 (1982) 5, p.11-14, 17-20, 23-24.
- 5 J.W.Boyes, Development and use of an abrasion test for cast irons and steels. *Iron and Steel* 42 (1969) 1, p.57-63.
- 6 F.Borik, D.L.Sponseller, W.G.Scholz, *J. Mat.* 6 (1971), p.675-605.
- 7 M.J.Fallon, BCIRA Report 1606, *BCIRA Journal* (1984), p.463-469.
- 8 Ni-Hard – Engineering Properties and Applications. Nickel Development Institute NiDI Publication No. 70 See also: Die verschleissfesten Ni-Hard- Werkstoffe, International Nickel, 1967.
- 9 G.J.Cox, Verschleissbeständige Gusseisenwerkstoffe unter besonderer Berücksichtigung von Ni-Hard. *Giesserei Praxis* (1990) 17, p.274-285.
- 10 J.Dodd, J.L.Parks, Einflussfaktoren auf die Herstellung und die Gebrauchseigenschaften dickwandiger Gussstücke aus hochlegierten Chrom- Molybdän-Gusseisen. *Giesserei-Praxis* (1979) 11/12, p.181-201.
- 11 G.J.Cox, Controlled cooling transformation diagrams for Ni-Hard alloy white cast irons. *Foundry Trade Journal* (1991), p.689-691.
- 12 H.Berns, W.Trojahn, Verschleissverhalten ledeburitischer Chromstähle mit Niob und Titan. *Z. Werkstofftechnik* 14 (1983), p.382-389.
- 13 H.Thoreson, Mindre slitage med ny legering. *Gjuteriet* 78 (1988) 3, p.6-8.
- 14 Unpublished Reports, Climax Molybdenum Co, Ann Arbor, MI, USA, 1975-1982.
- 15 G.L.Laird II, Microstructures of Ni-Hard I, Ni-Hard IV, and High Cr White Cast Irons. *Trans. Amer. Foundry Soc.* 99 (1991) 7, p.339-357.
- 16 B.K.Arnold, I.R.Sare, A thermal analysis study of alloy cast white irons. *Foundry* 80 (1987) 7, p.330-335.
- 17 M.N.Tomovic, D.V.Mihajlovic, M.M.Radulovic, Microstructure characteristics of isothermally treated Ni-Hard cast irons. *Trans. Amer. Foundry Soc.* 96 (1988), p.339-346.
- 18 R.H.T.Dixon, *J. Iron and Steel Inst.* 197 (1969) 1, p.40-48.
- 19 R.L.Pattyn, Heat Treatment of High Chromium White Irons. *Trans. Amer. Foundry Soc.* 101 (1993), Paper 93-001.
- 20 Groß- und Feinbearbeitung harter Eisenwerkstoffe mit PKB- Schneidstoffen. De Beers Industrial Diamond Division.
- 21 Data Sheets of De Beers Industrial Diamond Division.
- 22 I.Brunner, In reference 20.
- 23 J.L.Parks, Relationships between Brinell, Rockwell C and Vickers Hardness Values for Alloyed White Irons. *Trans. Amer. Foundry Soc.* 87 (1979), p.195-202.
- 24 R.Blickensderfer, J.H.Tyslak, G.L.Laird II, Spalling of High Chromium White Cast Iron Balls Subjected to Repeated Impact. *Wear of Materials*, Denver, CO, USA, April 9-13. 1989, p.175-182. Published by Amer. Soc. of Mech. Eng.
- 25 J. J. Fischer, "The Relationship of Microstructure to Properties in Ni-Hard 4", *AFS Transactions* (1983), pp. 47-54.
- 26 S. I. Karsay, "Ductile Iron, The State-of-the- Art 1980", Pub. By QIT-Fer-et-Titane, Inc., Montreal, Canada







*knowledge for a brighter future*

**Nickel Institute**

[communications@nickelinstitute.org](mailto:communications@nickelinstitute.org)

[www.nickelinstitute.org](http://www.nickelinstitute.org)

Published 2021

.....