

# Ni-Hard

## Material Data and Applications

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, pulverizer rings and roll heads, slurry pump parts, pipes and elbows, wearbacks and metalworking rolls—the range of properties inherent in the different grades of Ni-Hard has made it a worldwide success.

This book updates information for users on Ni-Hard's material data and applications.

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# Introducing Ni-Hard

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:

- the medium alloyed Ni-Hard 1 and Ni-Hard 2 with, nominally, 3.3% (resp 2.6%) C, 4% Ni, 2% Cr
- Ni-Hard 4 with, nominally, 3% C, 9% Cr, 5% Ni, 2% Si.

These three alloys are standardized in almost all industrialized nations under various designations.

Machined rollers for the clay and brick industries in Ni-Hard 1 and Ni-Hard 4.



## 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.

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). 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. 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.



NORCAST INC. TORONTO, CANADA

Grinding mill liner plate

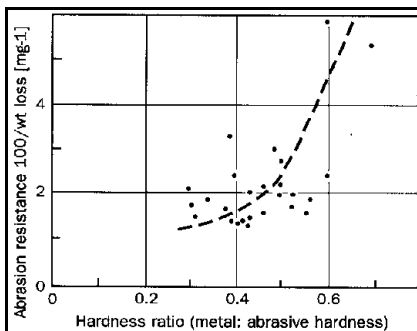


Figure 1. Variation of abrasion resistance in a lab test with the ratio of the hardness of white iron to the abrasive hardness<sup>12</sup>

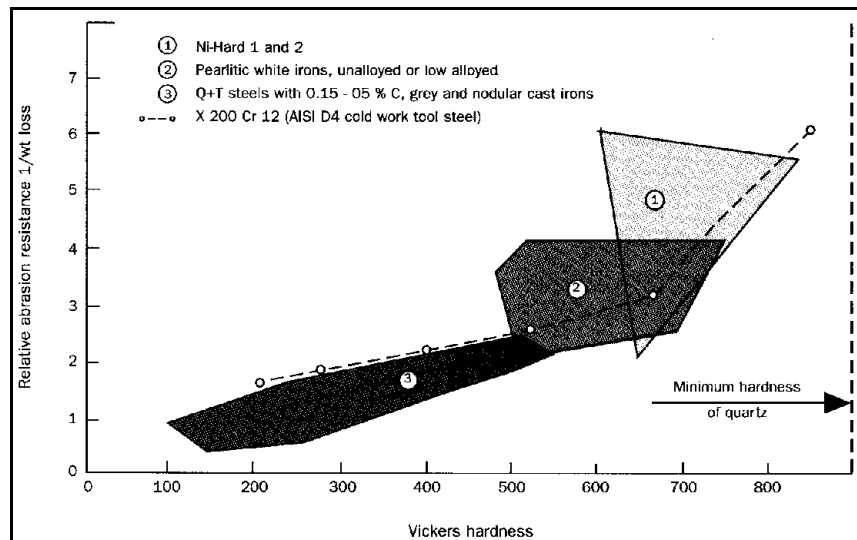


Figure 2. Abrasion resistance of various iron base alloys as influenced by their hardness. Wear pot test with quartz<sup>3,4</sup>

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.

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

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 recognized 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, Ni-Hard's abrasion resistance is higher than that of a Q+T 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.

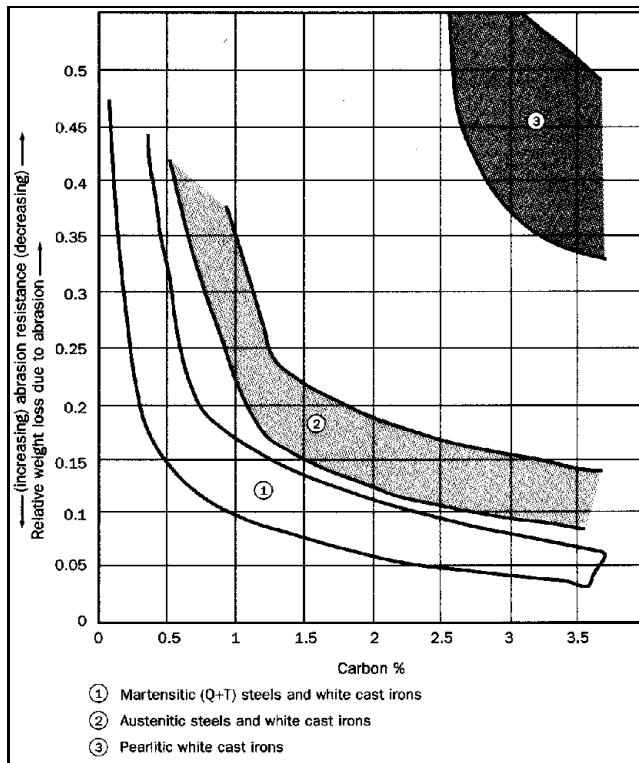


Figure 3. Abrasion resistance versus carbon content and microstructure of various white irons and steels



A 30-inch bottom or casing used in the production of concrete pipe. The Ni-Hard casing is machined using a CBN insert

TEXALLOY FOUNDRY, FLORESVILLE, TEXAS, USA

## 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. So results are often meaningless and can be more representative of testing conditions and operator skill than of the material properties.

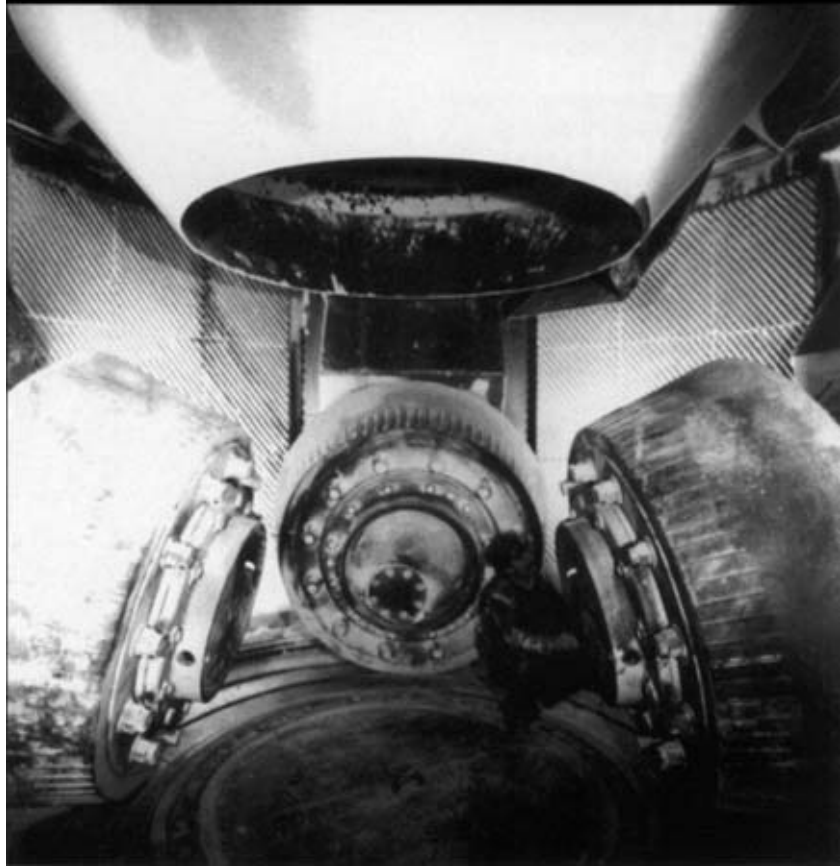
Generally, a decrease of the carbon (resp. carbide) content and rounded or discontinuous carbides improve the toughness.

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 in a particular application. The 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. So the integrity of the castings and the care and control used in heat treatment are decisive factors in service performance.

### Ni-Hard in use



Loescher roller pulverizer mill with Ni-Hard 4 rollers (each 3 tons) and table. Used for coal crushing in power stations, and in cement and mineral processing plants

LOESCHER GmbH, DÜSSELDORF, GERMANY

### Ni-Hard in use



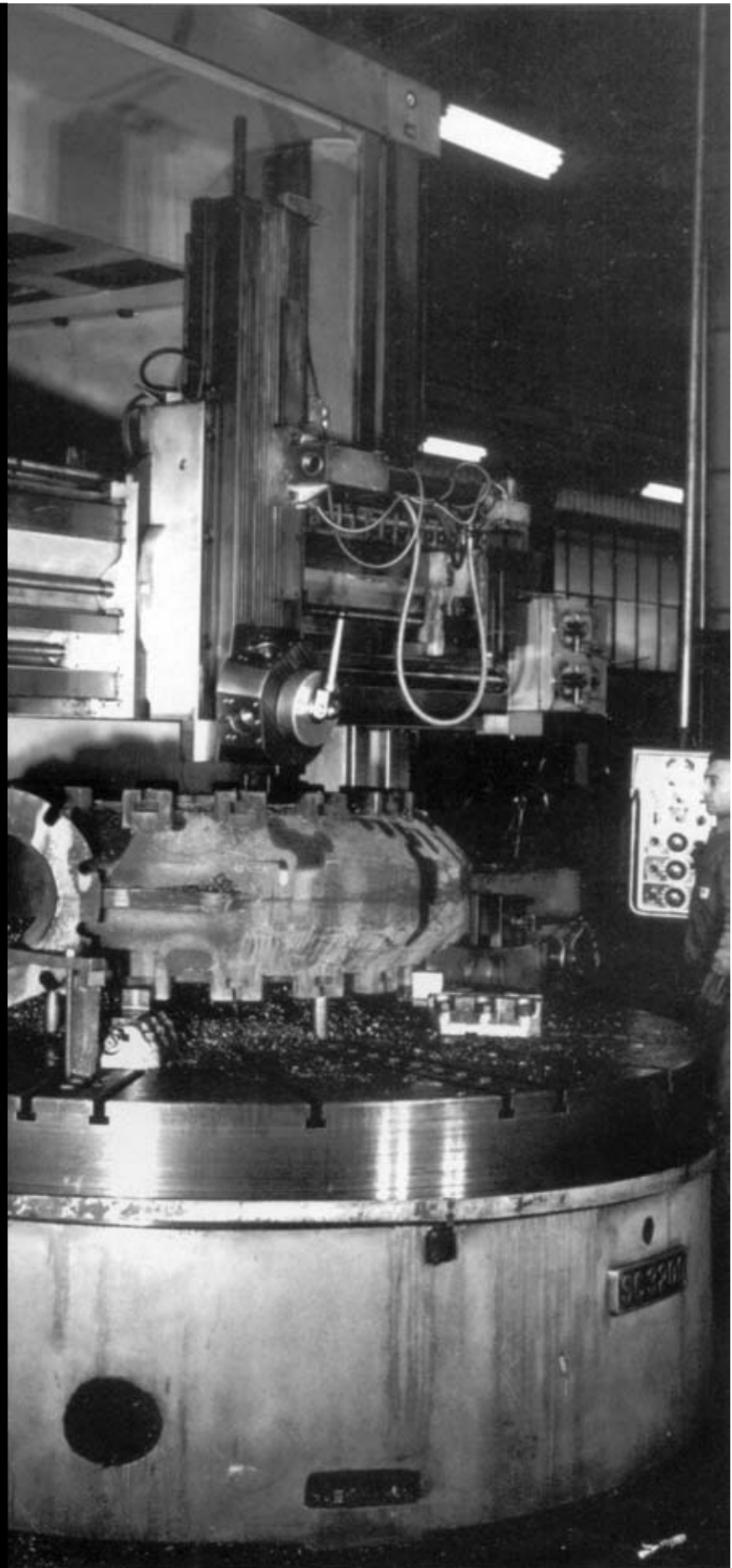
Ni-Hard 1 slurry pump impellers

STEEL CASTINGS, MELBOURNE, VICTORIA, AUSTRALIA

## 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.

Machining the Ni-Hard 1 casing of a slurry pump



FONDERIA COLOMBO, SAN GIORGIO SU LEGNANO, ITALY

## Standard Ni-Hard 1 and 2

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

### 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.

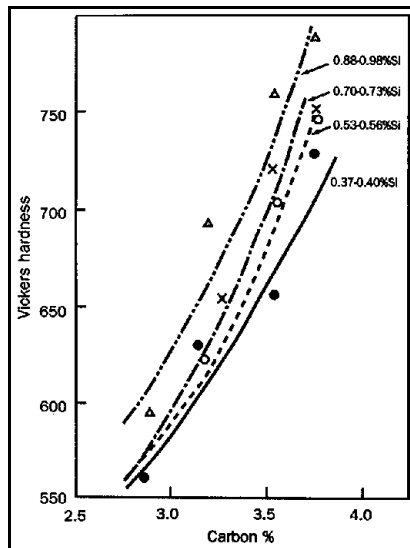
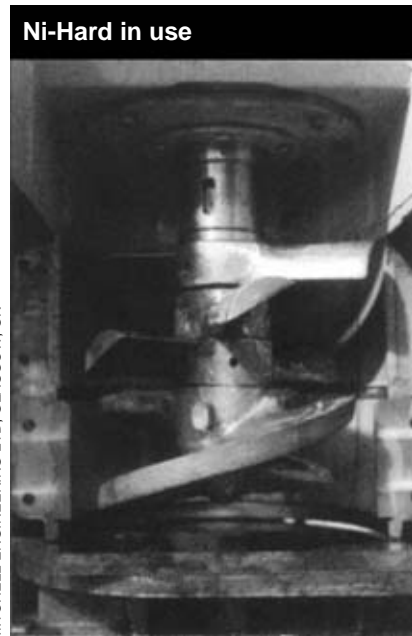


Figure 5. Effect of carbon content on hardness of Ni-Hard 1 in the as-cast condition at various silicon levels <sup>7</sup>



A vertical pug with a Ni-Hard spiral knife and mould

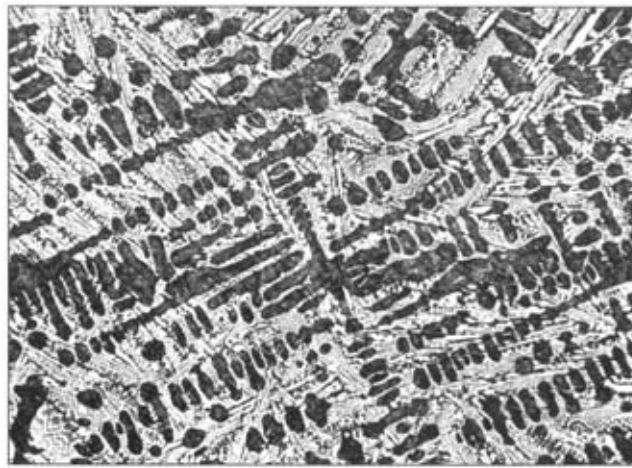
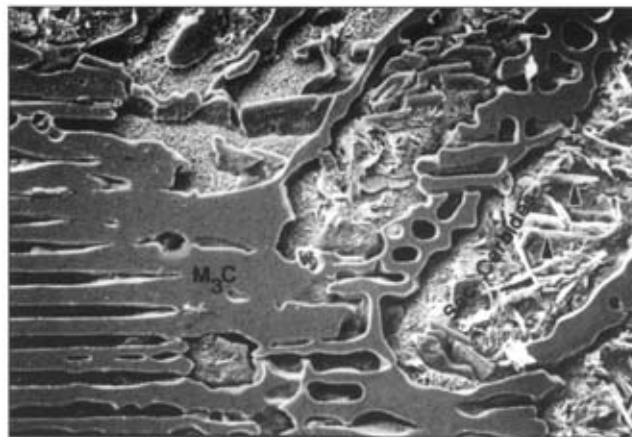


Figure 4. Microstructure of Ni-Hard 1 in the as-cast condition

Primary dendrites and eutectic



Optical micrograph. The eutectic  $M_3C$  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>

Table 1 • Compositions of the Ni-Hard irons

Grade	Chemical composition (weight %)							
	C (total)	Si	Mn	S	P	Ni	Cr	Mo*
Ni-Hard 1	3.0-3.6	0.3-0.5	0.3-0.7	max 0.15	max 0.30	3.3-4.8	1.5-2.6	0-0.4
Ni-Hard 2	max 2.9	0.3-0.5	0.3-0.7	max 0.15	max 0.30	3.3-5.0	1.42.4	0-0.4
Ni-Hard 4	2.6-3.2	1.8-2.0	0.40.6	max 0.1	max 0.06	4.5-6.5	8.0-9.0	0-0.4

\* in special cases



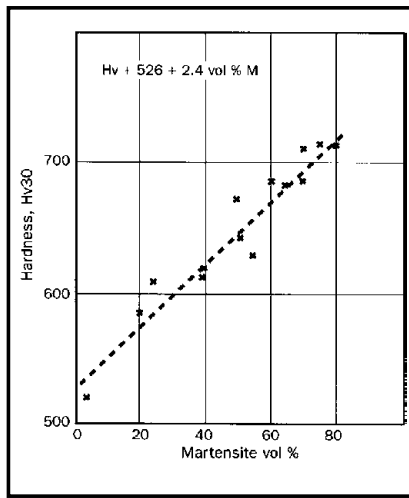


Figure 6. Effect of matrix martensite content on the hardness of Ni-Hard 2 casting tempered at 270°C (525°F) <sup>2</sup>

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

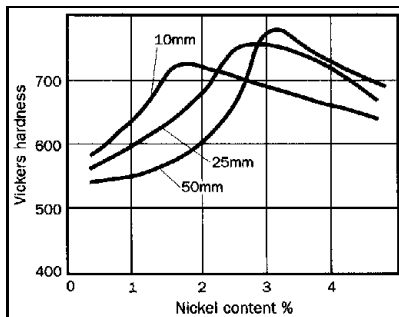


Figure 7. Hardness of as-cast Ni-Hard 1 in various sections as a function of the nickel content<sup>8</sup>



Ni-Hard 2 slurry pump with casing and impeller

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.

Ni-Hard 2's lower carbon content gives more primary dendrites at the expense of the carbide content. This results in a lower hardness and abrasion resistance but a higher toughness.

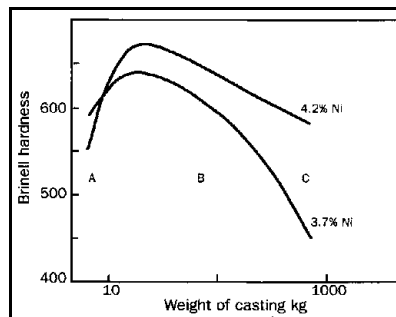


Figure 8. Effect of nickel on the as-cast hardness of Ni-Hard 1. Zone A is a region where a lower nickel content should be used in order to avoid excessive austenite formation. In zone B the 4.2% Ni irons have a satisfactory matrix, whilst 3.7% Ni irons fall away in hardness as significant amounts of 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>8</sup>

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 and the cooling rate, as indicated in Figures 7 & 8. The hardness maximum providing best abrasion resistance corresponds to the nickel content producing the maximum amount of martensite in each section. At lower nickel contents, hardenability is not sufficient 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 moulds.



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

Section in mm	Ni-Hard 1				Ni-Hard 2			
	Sandcast		Chillcast		Sandcast		Chillcast	
	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

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



**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%**

### Silicon

Silicon is a graphitizer and has to be kept to a low level in order to avoid the formation of graphite which reduces abrasion resistance. Decreasing the silicon content to below the range indicated in Table 1 is not recommended, however, because a certain amount of silicon is necessary to avoid foundry 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 page 10).

### Manganese

The manganese content of Ni-Hard should be kept at about 0.5%. Manganese increases hardenability and complements nickel in this respect. However, its power to suppress pearlite formation is much lower than its effect on austenite stabilization. Attempts to maintain equal 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.

### 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.

### Ni-Hard in use



Grinding media

## 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.

### 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 graphitizing effect of silicon has to be compensated by an increased chromium level and a ladle addition of about 0.015% Bi. The recommended Cr-Si ratio is 2.5:1 for light sections and 2.9:1 for heavy sections. Silicon also reduces hardenability, so 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 so that the bulk hardness of this alloy can reach 1,000 DPH after

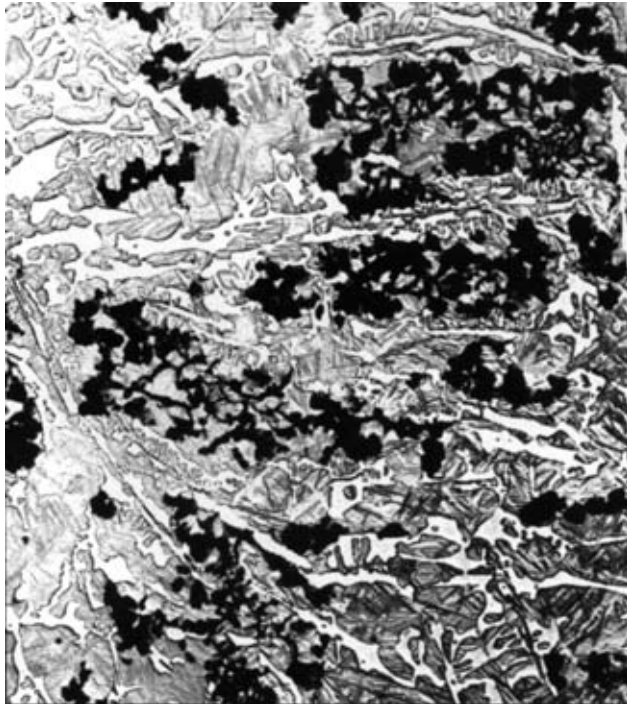
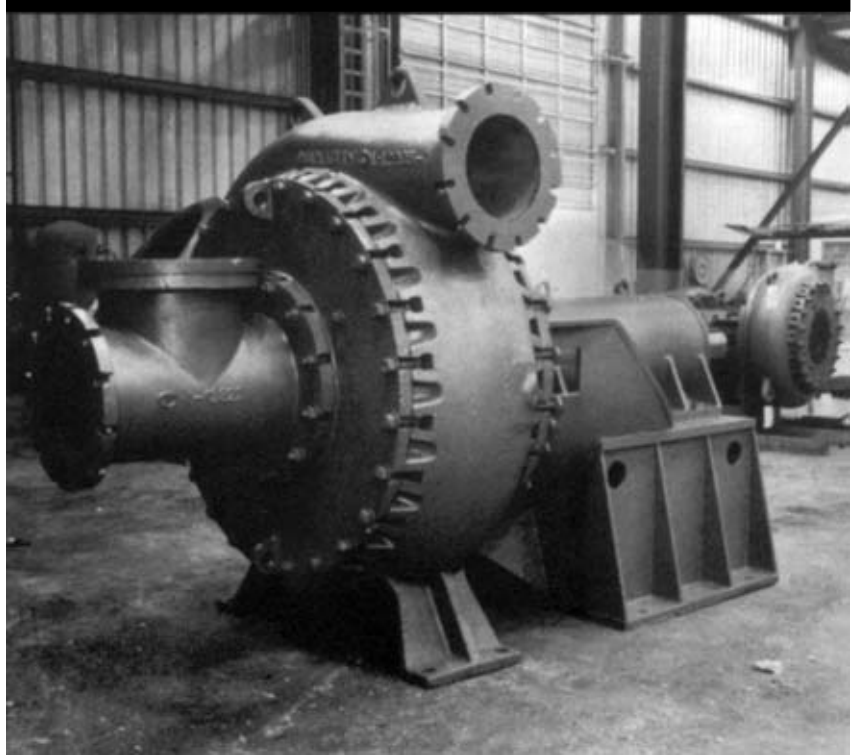


Figure 10. Structure of an "IndefiniteChill" roll with graphite stringers about normal to the surface, following the segregation zones parallel to the eutectic. The matrix is predominantly martensitic-bainitic

## Ni-Hard in use



Ni-Hard 4 underwater dredge pump – 36 cm suction; 8,900 kg total weight

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 mould 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 graphitizing 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 TiC carbides with an extremely high hardness of about 3,200 HV. They are precipitated from the melt at temperatures of about

1,700°C - 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 pulverizer 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 has to 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 VC or NbC particles in a Ni-Hard matrix with improved abrasion resistance<sup>14</sup>.

#### Ni-Hard 4

Ni-Hard 4 is a 9 Cr-6 Ni-2 Si white iron designed to give a structure with rod or blade like eutectic  $(Cr,Fe)_3C_3$  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 joint effect of the balanced chromium, nickel and silicon contents with a eutectic or slightly hypo-eutectic 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%.

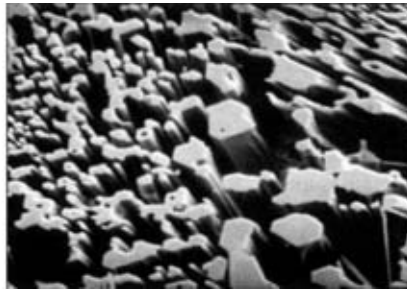
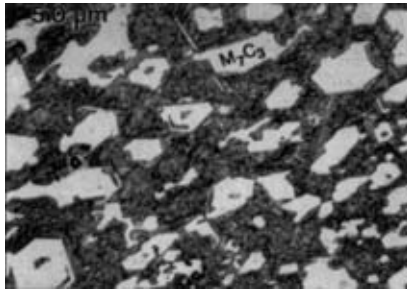


Figure 11. Eutectic microstructures of Ni-Hard 4<sup>15</sup>. Rod-like eutectic carbides are clearly visible (right).

#### Ni-Hard in use



Castings for coal crushers

BRAGONZI, LONATE POZZOLO, ITALY

The composition is shown in Table 3.

### Carbon

The carbon content of Ni-Hard 4 gives a eutectic or slightly hypo-eutectic 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.

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

### 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 casting, but a minimum of about 5% Ni should be maintained to avoid pearlite formation during slow cooling in the mould or during heat treatment. Higher nickel contents than 6.5% will stabilize 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.

**Table 3 • Nominal composition of Ni-Hard 4 (weight %)**

C	Si	Mn	Ni	Cr	S	P
2.8-3.0	1.9	0.5	5.5	8.5	≤0.05	≤0.07

### 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, and the carbon content on the high side of the range. So a target for silicon content of between 1.8 and 2.0% is recommended.

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 stabilization of the austenite. So 0.5 to 1.5% Mo can be added to increase the hardenability in heavy and very slowly cooled castings. This is preferred to raising the nickel content above 6.5%.

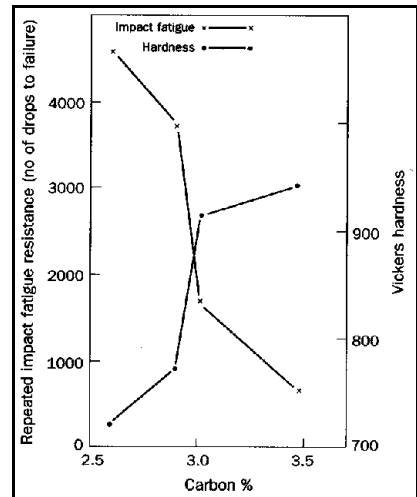


Figure 12. The effect of carbon content on hardness and impact resistance of heat-treated Ni-Hard 4

### 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. So an indefinite chill structure similar to 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.

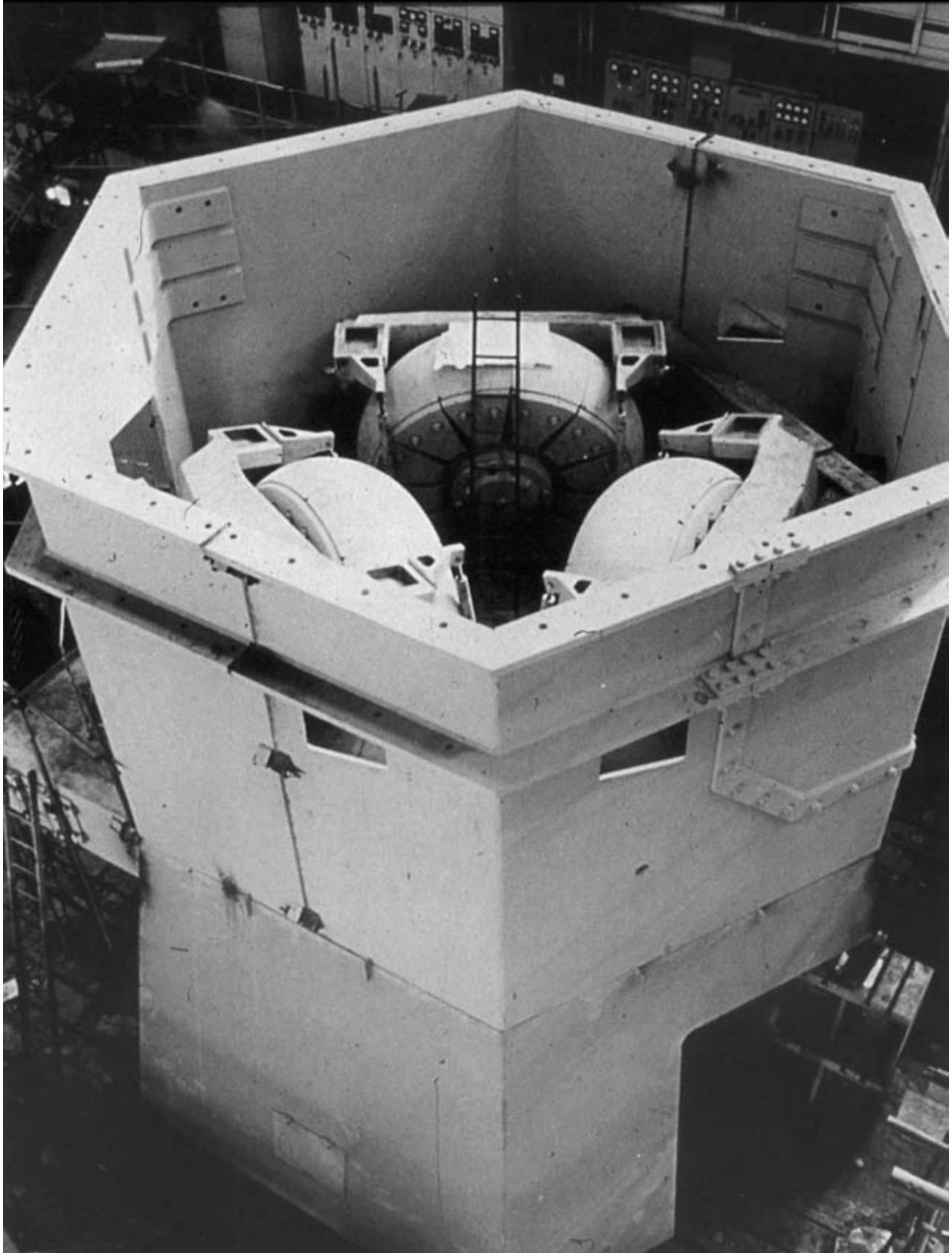
### Ni-Hard in use



Cyclone for a diamond mine

WUNDOWIE FOUNDRY, WUNDOWIE, AUSTRALIA

Ni-Hard in use



Inside view of MPS roller pulverizer mill with Ni-Hard 4 rollers and table

BABCOCK BLK GIEßEREI, OBERHAUSEN, GERMANY

## Ni-Hard production

In considering production practice, the Ni-Hards should be recognized as high-strength ferrous materials. 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.

Machining a crusher roll



## Moulding and methoding

All sands and binder systems used for gray and ductile cast irons or steel castings can be used to make moulds 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 has to be recognized 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 moulds.

Casting Ni-Hard 1 or 2 against a chill or in chill moulds 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 13. This contrasts with high-chromium irons or 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; so their shrinkage behaviour 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

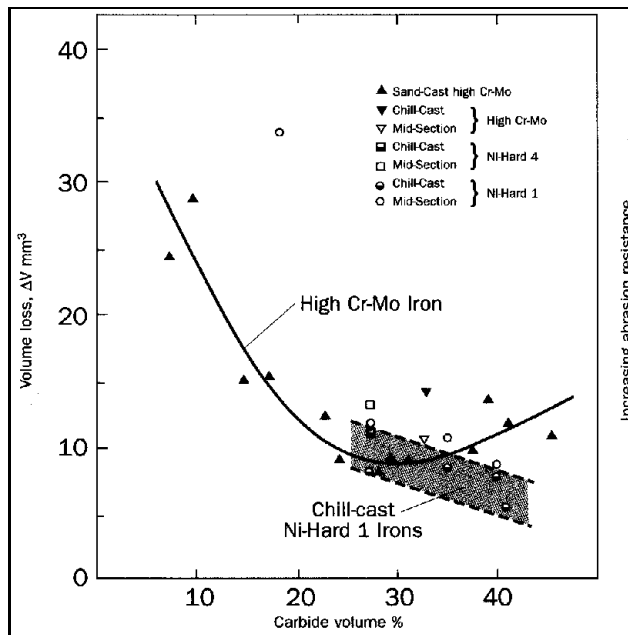


Figure 13. Relation between carbide volume and abrasion resistance determined in the rubber wheel abrasion test with sand and chill cast Ni-Hard 1 and high chromium irons<sup>14</sup>

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% (1/8 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%.

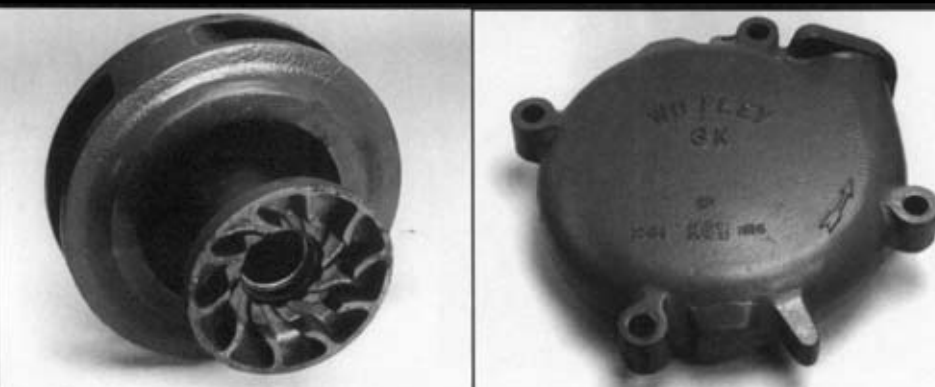
Shrinkage depends on the amount of retained austenite in the matrix because austenite has a higher shrinkage coefficient than martensite. This results in a peculiarity which must be kept in mind. The casting has an austenitic matrix after solidification and shrinks with a factor close to 3% until the transformation of austenite to martensite starts. This is at about 250°C for Ni-Hard 1 and 100°C for Ni-

Hard 4. This transformation is accompanied by a volume increase so 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 mould to below 50°C. Large castings can be shaken out early and then covered with insulating material to cool slowly almost to ambient.

## Ni-Hard in use



Ni-Hard 4 slurry pump casing and runner/impeller for moving liquids containing solid particles – used in mining, fertilizer, cement, coal, sugar, and chemical industries



## Melting

Ni-Hard 1 was originally designed for cupola melting, but today the use of electric or other batch 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 carburization 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 has to 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 1,600°C 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 to avoid excessive oxygen pickup, grain coarsening and deterioration of the carbide morphology.

The tapping temperature is usually 1,450 to 1,480°C.

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. 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.

Ni-Hard in use



TAYLOR GROUP, LARBERT, UK

Casing in Ni-Hard 4 for sugar beet pump (900 kg)

## Casting

The liquidus and solidus temperatures of the Ni-Hards are higher than those of normal cast irons. Figures 14 and 15 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 in order to give a fine-grained carbide structure. The usual range is between 1,350 and 1,400°C, depending on the type and section of the casting.

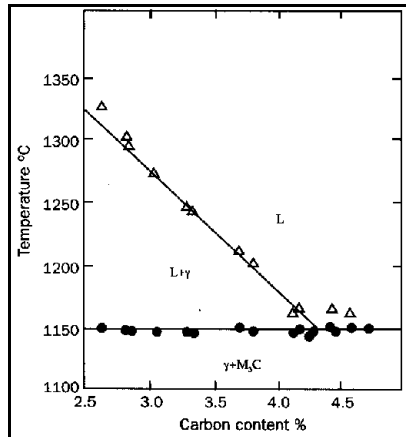


Figure 14. Partial quasi-binary phase diagrams for Ni-Hard 1 and 2<sup>16</sup>

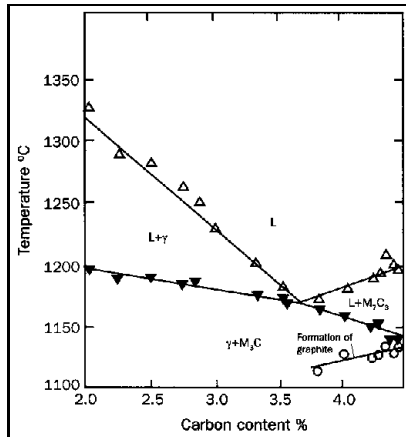


Figure 15. Partial quasi-binary phase diagrams for Ni-Hard 4<sup>16</sup>

## Bi-metallic 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 bi-metallic or compound castings.

### Bi-metallic castings

Ni-Hard 1 and 2 are especially suited for bi-metallic 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 behaviour and expansion coefficients of the two different materials.

**Bi-metallic 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 mould with sand moulded journals is first completely filled with Ni-Hard melt. The solidification starts from the chill, moving toward the centre of the body. After a specific

time only the centre and the sand moulded journals are still liquid. The second melt is then poured through the same gate at the bottom of mould. Rising in the mould, it pushes the remaining Ni-Hard melt out through the top journal until the core and the journals are filled with softer material.

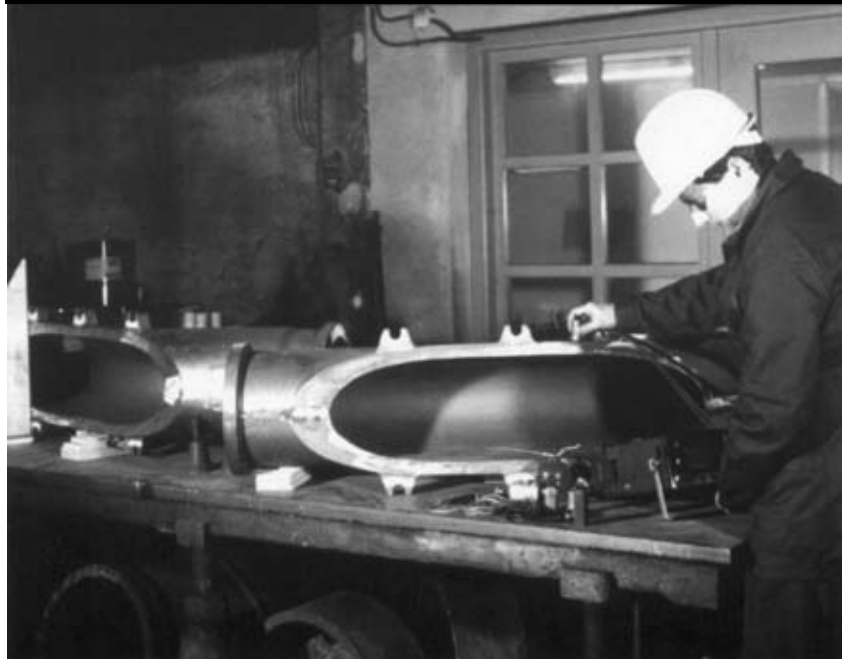
This deceptively simple technique obviously does not apply to castings of different and more complex shape. Here, more sophisticated methods have to be applied to achieve bonding without too much mixing. Sometimes a sheet of steel or nickel serves to separate the two melts for a specific time.

**Centrifugal casting** is a technique well suited to the production of bi-metallic 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.

### 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

### Ni-Hard in use



Checking the thickness of a bend for piping ashes and pulverized coal

FONDERIA COLOMBO, SAN GIORGIO SU LEGNANO, ITALY

taken to avoid a metallic bond of the steel rods to the cast metal in order to avoid embrittlement by carburization 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 has to 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 (*single-stage tempering*)
- improved repeated impact fatigue resistance by a duplex treatment at 450 + 275°C (*double-heat treatment*)
- improved hardness and abrasion resistance by soaking at 750-850°C, 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 16.

**Single-stage tempering** The single-stage tempering heat treatment at 225-275°C leads to:

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

The main rationale for this heat treatment is the first of these. 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. So it is often advisable to carry out fettling and finishing

### Ni-Hard in use



FONDERIA COLOMBO, SAN GIORGIO SU LEGNANO, ITALY

Grinding ring for coal pulverisers

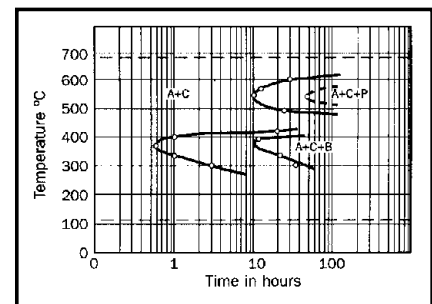


Figure 16. Typical isothermal transformation diagram of Ni-Hard 1<sup>17</sup>

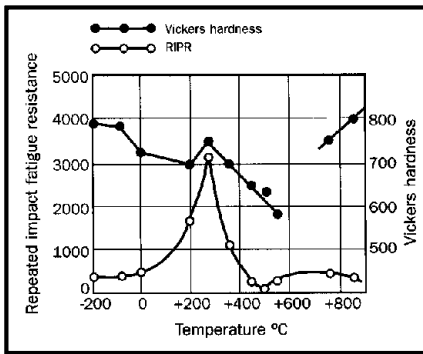


Figure 17. Hardness and repeated impact fatigue of Ni-Hard 1 after tempering at various temperatures<sup>18</sup>

operations after stress relief heat treatment.

The effect of this heat treatment on properties can be seen in Figure 17. Tempering of the martensite reduces hardness while repeated impact fatigue resistance increases due to relief of stress. At about 275°C, some retained austenite is transformed to martensite, which improves hardness and especially repeated impact fatigue resistance. Above 275°C, 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 and vice versa. Figure 18 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

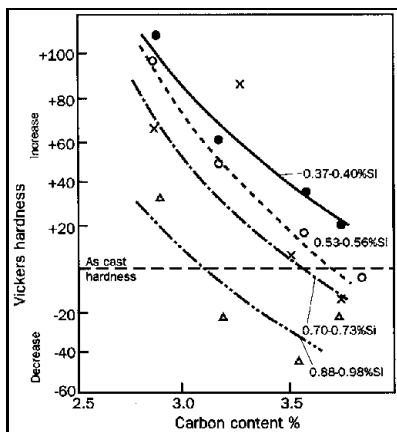


Figure 18. Variation of hardness between tempered (285°C, 14 h) and as-cast Ni-Hard 1 irons having different carbon and silicon levels<sup>7</sup>

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 16) 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. The martensite already present in the as-cast structure will be heavily tempered and lose hardness.

Figures 19 and 20 show the change in hardness resulting from the duplex treatment at different carbon and silicon contents. The effect is similar to the single-stage heat treatment shown in Figure 18.

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.

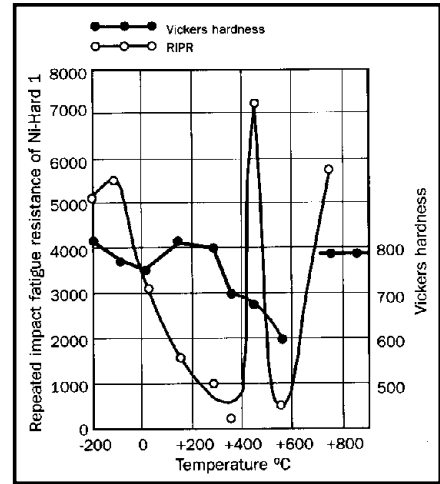


Figure 19. Hardness and repeated impact fatigue after double heat treatment at 450 + 275°C<sup>18</sup>

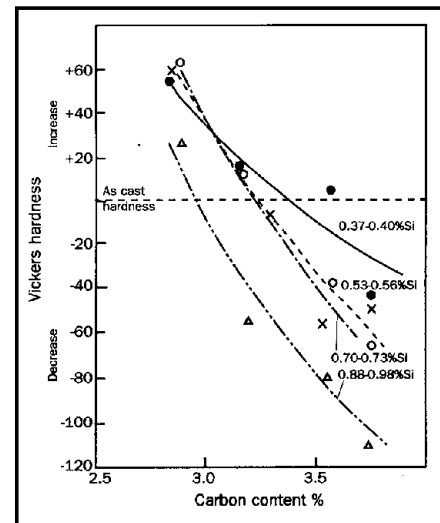
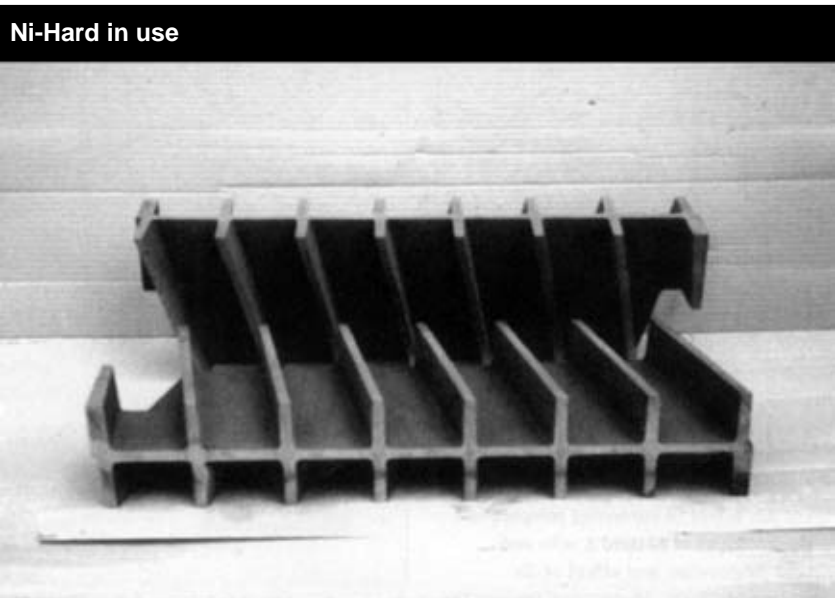


Figure 20. Variation of hardness between double-heat-treated (460°C, 5 h + 285°C, 14 h) and as-cast Ni-Hard 1 irons having different carbon and silicon levels<sup>7</sup>



Power station riffle plates for directing pulverized coal, Ni-Hard 1

WEAR PARTS LTD, LUTTERWORTH, UK

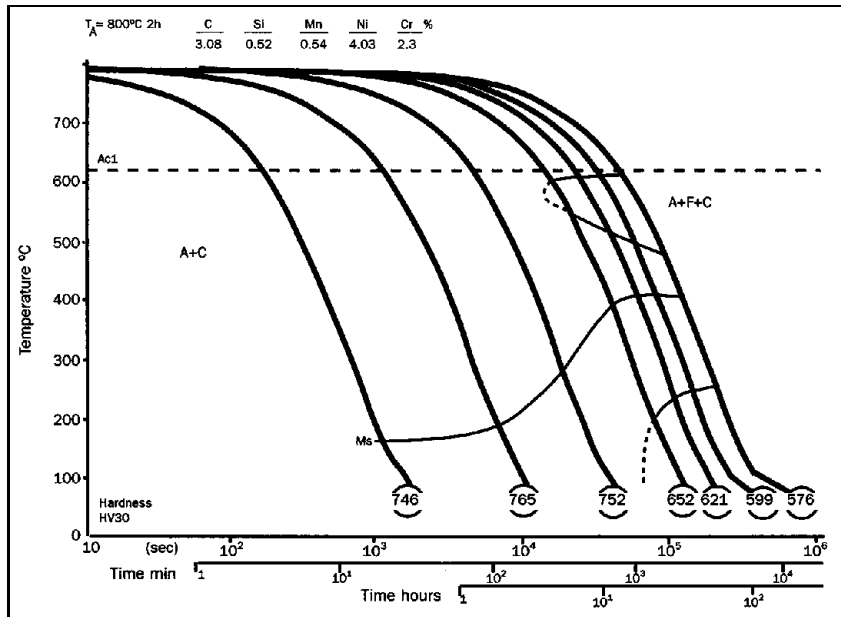


Figure 21. Continuous cooling transformation diagram of Ni-Hard 1<sup>11</sup>

**Hardening** Hardening by high-temperature heat treatment can be followed in the continuous cooling transformation diagram, Figure 21. 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  $M_s$  temperature and facilitates transformation to martensite during cooling to ambient. During slow cooling, more carbides are precipitated so that the  $M_s$  temperature increases further, as seen in Figure 21. At the same time a certain self-tempering of the martensite results in some loss of

that hardness during cooling from  $M_s$  to ambient. So 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 22. A low hardening temperature will give a lower carbon content in the austenite which lowers the hardness of the

resulting martensite and also somewhat reduces hardenability. Hardening from high temperature will stabilize 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 to 750°C 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 4 – see page 22). 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 vaporizing liquid nitrogen in an insulated chamber. Figure 23 shows the results. Since similar and higher as-cast hardness values can be reached with optimized compositions, such treatment has not achieved commercial significance. This treatment may be considered for hardening complex castings where heat treatment is considered too risky.

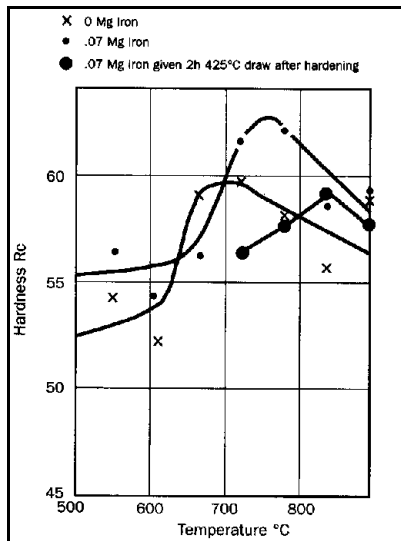
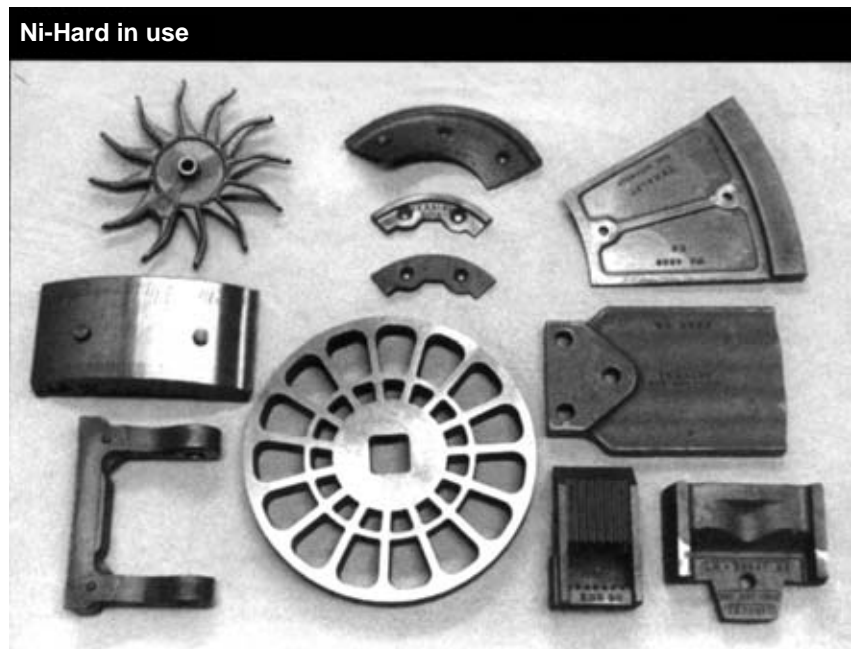


Figure 22. Effect of hardening temperature on the hardness of Ni-Hard 1 with and without magnesium and effect of 2h tempering at 205°C. Magnesium favours the martensitic transformation<sup>2</sup>



A variety of Ni-Hard 1 castings used in aggregate processing, slag and glass crushing mill, concrete pipe machine, and agriculture

TEXALLOY FOUNDRY, FLORESVILLE, TEXAS, USA

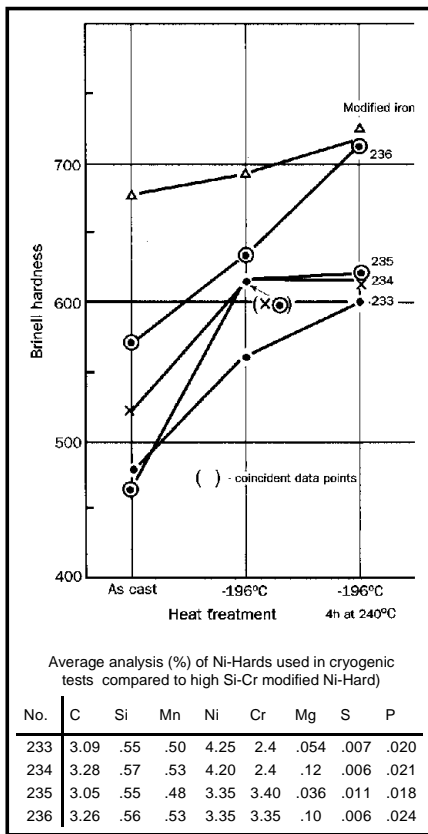


Figure 23. Effects of a subzero treatment, a subsequent tempering and magnesium addition on the hardness of Ni-Hard 1<sup>2</sup>

#### 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 destabilization or conditioning of the austenite at temperatures above 750°C, where austenite stability is lowered by carbide precipitation. Figure 24 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 destabilization temperatures of 820-860°C 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 25 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 sufficient to allow cooling rates of less than 20 K/h through the temperature



Loesche rolls for coal and cement grinding and roller for the clay and brick industry in Ni-Hard 4.

SCHWÄBISCHE HÜTTENWERKE, KÖNIGSBRUNN, GERMANY

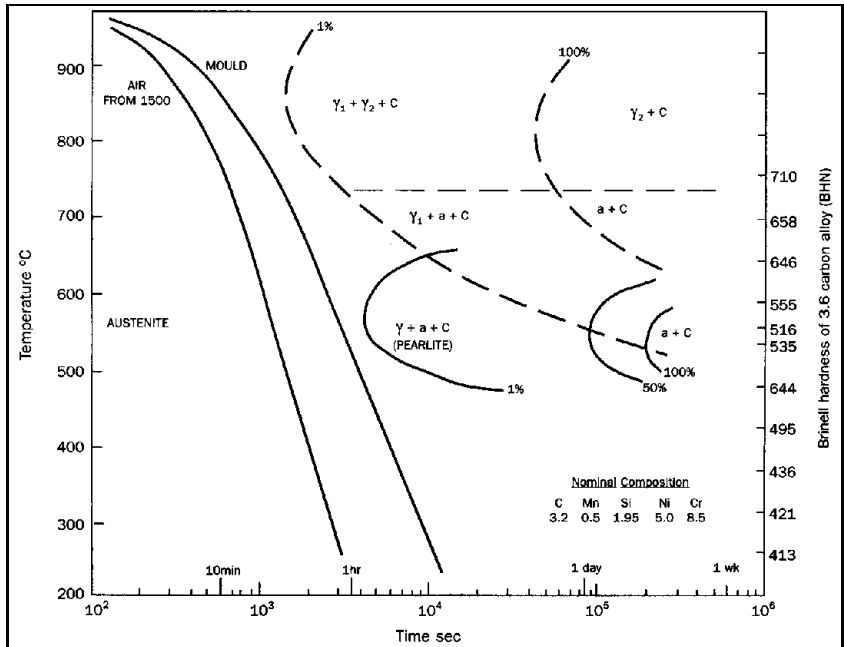


Figure 24. Isothermal transformation diagram of Ni-Hard 4

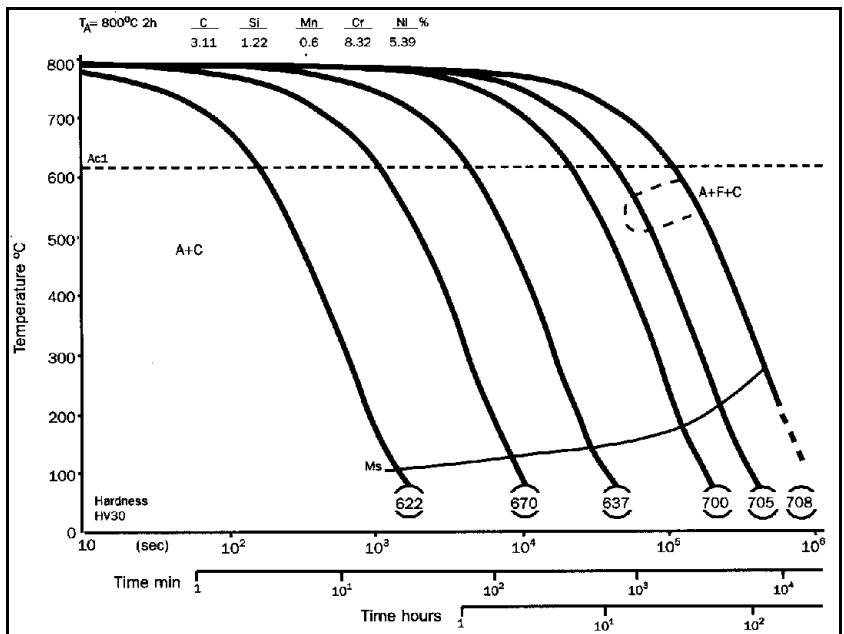


Figure 25. Continuous cooling transformation diagram of Ni-Hard 4<sup>11</sup>

range between 600 and 300°C without pearlite formation. Excellent hardness values have also been observed after air cooling to about 600°C 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 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 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. This may increase hardness even further.

**Sub-critical heat treatment** A sub-critical heat treatment of 4 to 8 hours at 550°C followed by 16 hours at 450°C 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>.

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 minimize 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.

Ni-Hard in use



MITCHELL COITTS ENGINEERING, PERTH, AUSTRALIA

Heavy medium slurry distributor in Ni-Hard 1



## 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. 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.

## 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 work piece 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 4 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
Feed rate during roughing	0.4 mm
Feed rate during finishing	0.25 mm

The risk of breaking the expensive 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.

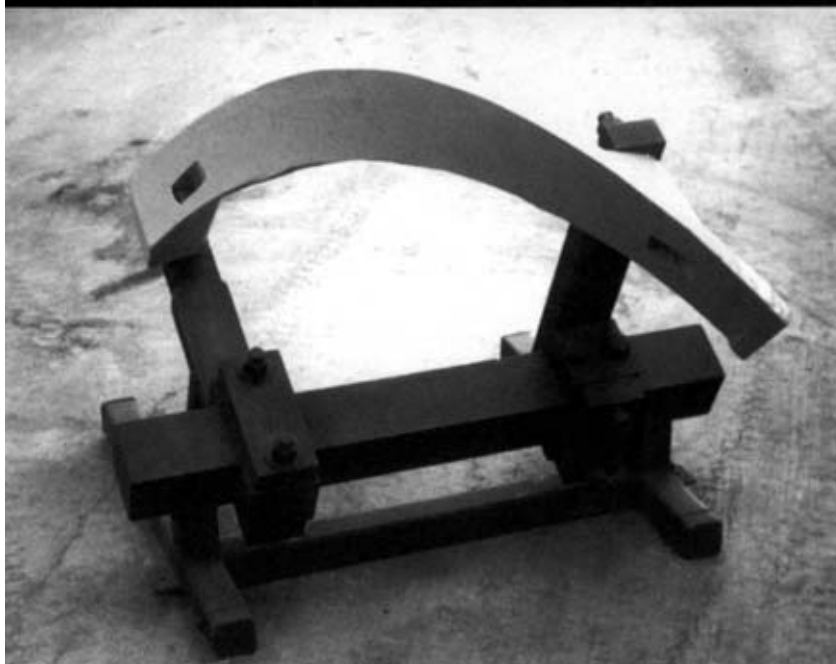
Drilling holes and tapping is also possible with CBN provided the diameter is large enough. For small holes, cast-in mild steel inserts are often used. The inserts must be clean and dry in order to avoid defects by reaction with the melt. The remaining Ni-Hard section must be high enough to avoid cracking. 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 has to be taken to avoid bursting a too thin remaining Ni-Hard section while screwing in the insert.

**Table 4 • Suggested machining conditions for turning of Ni-Hard with 570 to 750 HBN with CBN<sup>21</sup>**

Machining operation	Surface speed [m/min]	Maximum depth of cut [mm]	Feed rate [mm/rev]
Finishing	40 to 80	1.3	0.05 to 0.15
Light roughing	40 to 80	2.0	0.05 to 0.20
Rough turning	40 to 80	3.2	0.05 to 0.40

**Ni-Hard in use**



Concrete mixer blade in a jig to check the casting

# Ni-Hard properties

The typical range of mechanical and physical properties of Ni-Hard are shown in Tables 5, 6 and 7. The temperature dependence of some mechanical properties of Ni-Hard 1 and Ni-Hard 4 are shown in Figure 26 and Tables 8 and 9.



Pfeiffer roller pulverizer mill with segmented rollers and table in Ni-Hard 4 for limestone grinding, total weight around 80te

GEBR. PFEIFFER, KAISERSLAUTERN, GERMANY

**Table 5 • Typical range of mechanical properties of Ni-Hard 1 and 2<sup>8,14</sup>**

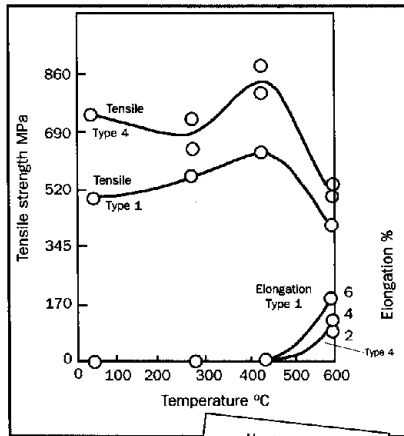
Type	Brinell	Hardness Vickers	Rockwell C	Tensile Strength [MPa]	Transverse Strength* [MPa]	Deflection* [mm]	Modulus of Elasticity [GPa]	Impact** Energy [J]	Fracture Toughness [MN/m <sup>3/2</sup> ]
Ni-Hard 1									
Sand cast	550-690	640-750	56-63	280-350	500-620	2.0-2.8	169-183	28-41	15-26
Chill cast	600-730	700-860	58-65	350-420	560-850	2.0-3.0	169-183	35-55	
Ni-Hard 2									
Sand cast	530-630	630-740	54-60	320-390	560-680	2.5-3.0	169-183	35-48	
Chill cast	580-680	680-800	57-62	420-530	680-870	2.5-3.0	169-183	48-76	

\* 30 mm dia, 300 mm span

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

**Table 6 • Some typical physical properties of Ni-Hard 1 and 2<sup>8</sup>**

Specific density [g/cm <sup>3</sup> ]	7.6-7.8
Thermal conductivity [W/mK]	
at 20°C	14-15
at 120°C	14.2
at 450°C	18.8
Between	
10 and 95°C	8-9
10 and 260°C	11.3-11.9
10 and 425°C	12.2-12.8



**Figure 26.**  
Temperature dependence of the tensile strength and elongation of Ni-Hard 1 and Ni-Hard 4

**Table 7 , 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]	500 - 600
Transverse strength [MPa]	600 - 800
Deflection [mm]	2.0 - 2,8
Compressive strength [MPa]	280 - 310
Modulus of elasticity [GPa]	190 - 200
Fracture toughness [MN/M <sup>3/2</sup> ]	19 - 30
Specific density [g/cm <sup>3</sup> ]	7.75
Thermal conductivity [W/mK]	12.6 - 15
Specific heat at 20°C [J/kgK]	500
Specific electrical resistance at 20°C [Ω.mm <sup>2</sup> /m]	
	0,85
Mean coefficient of linear thermal expansion [μm/mK]	
20 to 100°C	14.8
20 to 200°C	15.2
20 to 300°C	15.8
20 to 400°C	15.9
20 to 500°C	15.3

**Table 8 , Hot-hardness testing of a heavy section Ni-Hard 1 casting<sup>14</sup>**

Temperature [°C]	Hardness [HV 10]
205	606
315	521
425	485
480	416
540	308
595	201
650	138
760	92
815	75

**Table 9 , Elastic modulus of Ni-Hard 4<sup>8</sup>**

Temperature [°C]	Elastic modulus [GPa]
20	19 600
100	19 200
200	18 500
300	17 800
400	17 300
500	17 000
600	16 200
700	14 400
800	13 000

## Testing Ni-Hard castings

The most interesting 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 and impact 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 recognized in all standards where other properties than hardness are not specified.

Installing Ni-Hard 1 liner plates in a grinding mill



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**Table 10 • European standard designations of nearest equivalent grades**

International trade name	EU designation	EU number	France NF A 32-401	Germany DIN 1685	UK BS 4844	India IS 7925 IS 4771	Sweden SIS 14 04 XX SIS 14 05 XX	USA ASTM A532
Ni-Hard Type 2	EN-GJN-HV520	EN-JN2020	FB Ni4 Cr2 BC	G-X 260 NiCr 4 2	2A	Type 1a NiCr 30/500	0512	Class 1. Type B
Ni-Hard Type 1	EN-GJN-HV550	EN-JN2030	FB Ni4 Cr2 HC	GA 330 NiCr 4 2	2B	Type 1a NiCr 34/550	0513	Class 1. Type A
Ni-Hard Type 3			FB A	-		-	-	Class 1. Type C
Ni-Hard Type 4	EN-GJN-HV600	EN-JN2040	FB Cr9 Ni5	G-X 300 CrNiSi 9 5 2	2C+2D+2E	Type 1b NiHCr	0457	Class 1. Type D

**Hardness**

For hardness testing, the scientifically correct and also 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 have to be converted into one of the standard hardness scales.

It must be emphasized that the conversion tables or curves for steels or for graphitic cast irons do not apply to Ni-Hard. ASTM A-532 contains special conversion tables and formulas for the hardness values of white irons. It should be recognized that these formulas have been obtained by regression analysis<sup>23</sup> and that there is no exact linear relationship between the three scales.

So it is recommended that supplier and client agree beforehand on the hardness testing method, or at least on the conversion table.

**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-standardized drop-ball test machine, where balls repeatedly drop from a certain height (usually around 6 metres) 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. So this testing method gives only

a ranking of various materials. Generally, it has been found that higher retained austenite contents reduce impact fatigue resistance.

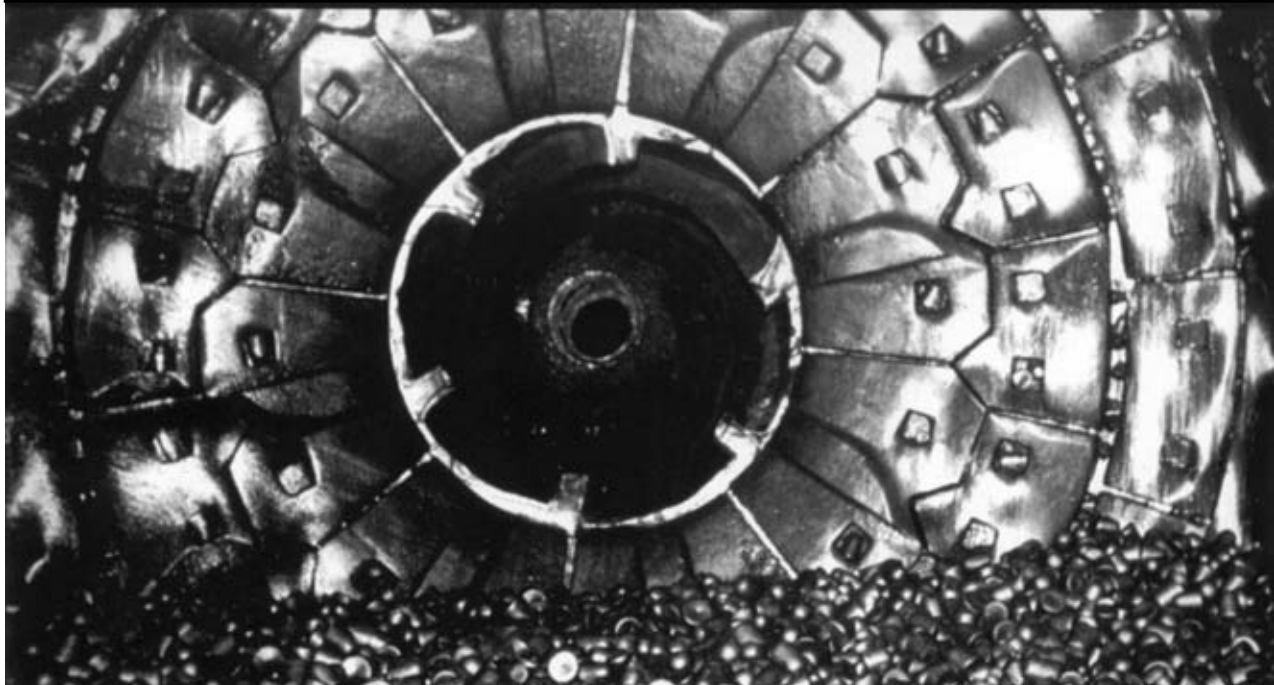
**Soundness**

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 10 indicates the various standard designations for these three alloys. ISO, Japan and Italy have no standards.

**Ni-Hard in use**



Ni-Hard 1 grinding media and liner plates inside a mill

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