TECHNICAL REPORT

ISO/TR 13393

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2009-07-01

Welding consumables — Hardfacing classification — Microstructures

Produits consommables pour le soudage — Classification des rechargements durs — Microstructures

Reference number
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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art”, for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 13393 was prepared by the *International Institute of Welding*, Commission II, *Arc Welding and Filler Metals*, which has been approved as an international standardizing body in the field of welding in accordance with Council Resolution 42/1999.

Requests for official interpretations of any aspect of this International Standard should be directed to the ISO Central Secretariat, who will forward them to the IIW Secretariat for an official response.

Introduction

Hardfacing is the deposition of a given type of alloy onto a substrate, in view of protecting this substrate against various types of degradation known under the name of wear. The science that deals with wear and wear mechanisms is called “tribology.”

In this sense, this Technical Report does not cover the surfacing processes and alloys that are commonly known under the name of “cladding technologies”, which more specifically address the protection of substrates against corrosion.

Hardfacing can be carried out by means of a large variety of alloys.

The selection of the optimum alloy to resist a given combination of wear factors is not necessarily an easy task. This task can, however, be facilitated by giving consideration to those attributes of alloys that are dominant in determining their behaviour and their properties.

In this sense, the microstructure of the alloys, which itself is determined by a composition and a thermo-mechanical history, certainly can be accepted as an attribute of major importance and significance.

It is the purpose of this Technical Report to propose a classification system of hardfacing alloys based on compositions and microstructures.

Since most of these alloys exist under the form of consumables that can be used with a variety of welding processes, no specific reference is made to these processes in the rest of this Technical Report.

Welding consumables — Hardfacing classification — Microstructures

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This Technical Report proposes a system for classifying hardfacing microstructures deposited by fusion welding processes.

2 Proposed classification/designation system

The designation system indicates the type of consumable (electrode; tubular cored electrode, wire or rod; solid wire or rod; or powder), the use of the consumable for hardfacing, the alloy base (iron, nickel, copper, cobalt, or tungsten carbide), and the microstructure type. Designations of microstructure types for the various alloy bases are given in Clauses 3 and 6. Definitions and examples of the microstructure types are given in Clauses 5 and 7. The designation scheme for a hardfacing deposit is given below:

E	**H**	**XX**	**XXX**
Electrode	Hardfacing type	Alloy base	Microstructure
T = tubular-cored electrode		**Fe** = iron base	
S = solid wire or rod		**Ni** = nickel base	
P = powder		**Cu** = copper base	
		Co = cobalt base	
		W = tungsten carbide base	

3 Summary of the designators for iron-base microstructures

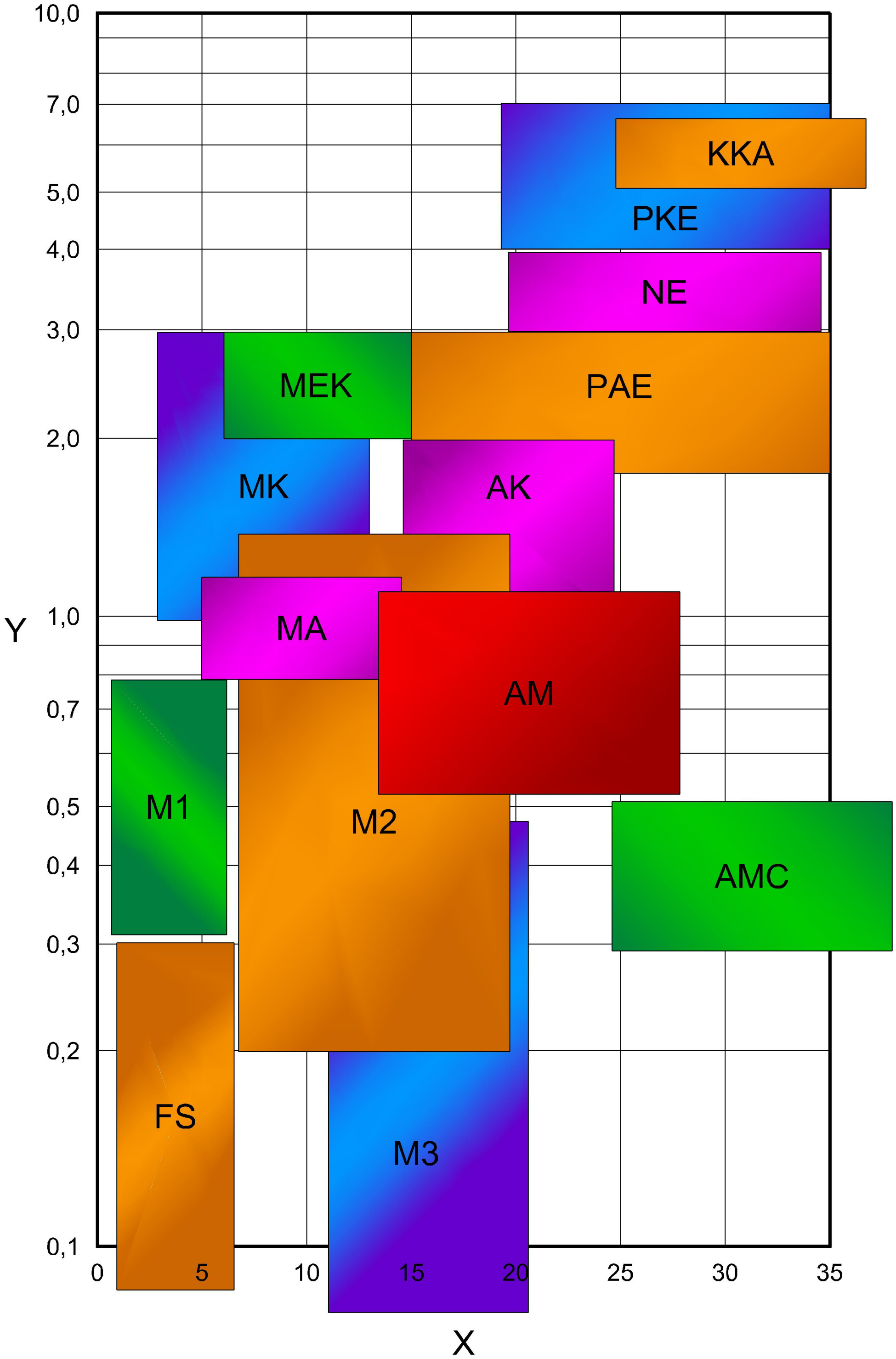
Most of the currently known Fe-based hardfacing alloys fall into one of about 17 typical microstructural categories. These types of microstructure are listed in Table 1, which also gives the proposed corresponding designators for covered electrodes. For convenience, only the E (electrode) form is shown, but it is understood that T (tubular-cored electrode), S (solid wire or rod), or P (powder) may be substituted for E.

Table 1 — Iron-base hardfacing deposit microstructure types

Hardfacing deposit designation	Microstructure type
E-H-Fe-FS	Mostly ferritic steel with second phase
E-H-Fe-M1	Low-alloy martensitic steel
E-H-Fe-M2	Tool steel martensite with secondary hardening
E-H-Fe-M3	Stainless steel martensite
E-H-Fe-M4	Maraging steel martensite
E-H-Fe-MA	Approximately equal amounts of martensite and austenite
E-H-Fe-MK	Martensite with alloy carbides
E-H-Fe-MEK	Martensite with austenite-carbide eutectic
E-H-Fe-A	Austenitic stainless steel with little or no ferrite
E-H-Fe-AF	Austenitic stainless steel with more than 30 FN
E-H-Fe-AM	Austenitic manganese steel with low or no chromium
E-H-Fe-AMC	Austenitic manganese steel with chromium nearly equal to manganese
E-H-Fe-AK	Austenitic manganese steel containing alloy carbides
E-H-Fe-PAE	Primary austenite with austenite-carbide eutectic
E-H-Fe-NE	Near-eutectic austenite-carbide iron
E-H-Fe-PKE	Primary chromium carbides with austenite-carbide eutectic
E-H-Fe-KKA	Primary chromium carbides with alloy carbides and austenite-carbide eutectic

4 Identification of iron-base alloy microstructural groups in a carbon/alloying elements diagram

A convenient and systematic way to correlate composition and microstructures of hardfacing alloys consists in using a diagram such as that given in Figure 1. On the ordinate, the mass fraction of carbon is plotted as a percentage using a logarithmic scale. On the abscissa, the total amount of alloying elements, also plotted as a percentage, is represented. Alloying elements include Cr, Mn, Si, Mo, Ni, Nb, V, W and Ti. These are the most commonly encountered alloy elements in Fe-based hardfacing alloys. In this diagram, based on compositional ranges and corresponding microstructures that are known for most of the alloys currently being used in practice, the domains which correspond to the types of microstructure listed in Table 1 have been delineated. It should be noted that these delineations are to be taken as guidelines, not absolutes. Transitions from one type to another type of microstructure are often progressive, and therefore, at least with alloys that are characterized by borderline compositions, a certain degree of overlap is to be expected in practice. Note that composition ranges for microstructure types A, AF and M4 are not included in Figure 1 because their mass fraction of carbon is below 0,1 %.



Key

X alloy, percent

Y carbon, percent

Figure 1 — Map of composition ranges for hardfacing microstructures

5 Description of the iron-base alloys belonging to the different microstructure groups

5.1 General

For each group, the following pages contain some general information as to the following topics:

- typical chemical composition ranges;
- as-welded microstructure;
- typical as-welded hardness range;
- typical response to post-weld heat treatment;
- impact resistance (as a qualitative judgment);
- metal-to-metal wear resistance (as a qualitative judgment);
- resistance against abrasive wear;
- corrosion resistance;
- high-temperature resistance;
- machineability;
- typical applications;
- typical microstructure illustrations.

5.2 Fe-FS Group (ferrite with second phase)

See Table 2.

Table 2 — Fe-FS Group

Typical composition:

- Up to 0,3 % C
- Up to 6 % alloying elements

Microstructure: Predominantly ferrite with small amounts of pearlite, bainite, martensite

Main characteristics:

- Hardness (as deposited): Generally expressed in HB, ranging from 200 HB to 400 HB, function of mass fraction of C
- Machineable in the as-welded condition, PWHT improves machineability
- Excellent impact resistance
- Good metal-to-metal wear resistance
- Low to moderate abrasion resistance (function of hardness)
- Hardness drops if heat treated
- Deposits rust
- Typical example: 0,25 % C, 3 % Cr

Applications: Build-up to return worn parts to original size, metal-to-metal wear as in pulleys, idlers, gears

Deposit made with preheating at 200 °C, cooled slowly, resulting in a hardness of 20 R_C.

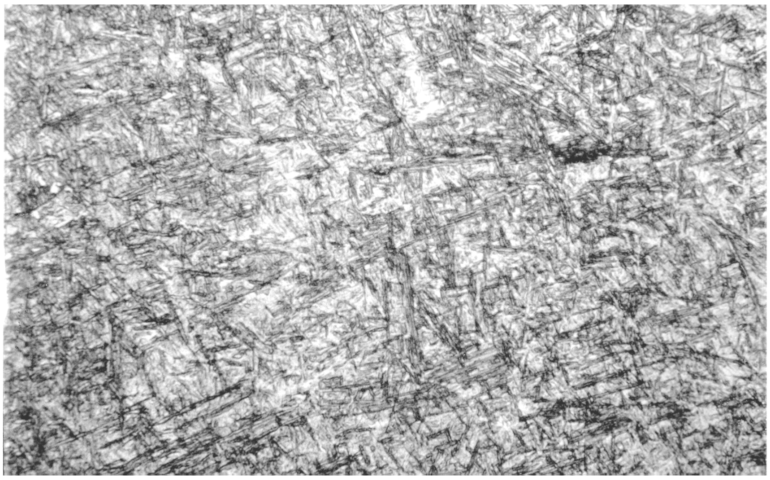
Microstructure is primarily ferrite with a little second phase.

Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type FS Deposit, ×650, 2 % Nital (alcoholic nitric acid) etch

(*continued*)

Table 2 (*continued*)



Deposit made without preheating, and allowed to cool rapidly, resulting in a hardness of 35 R_C.

Microstructure is heavily bainitic.

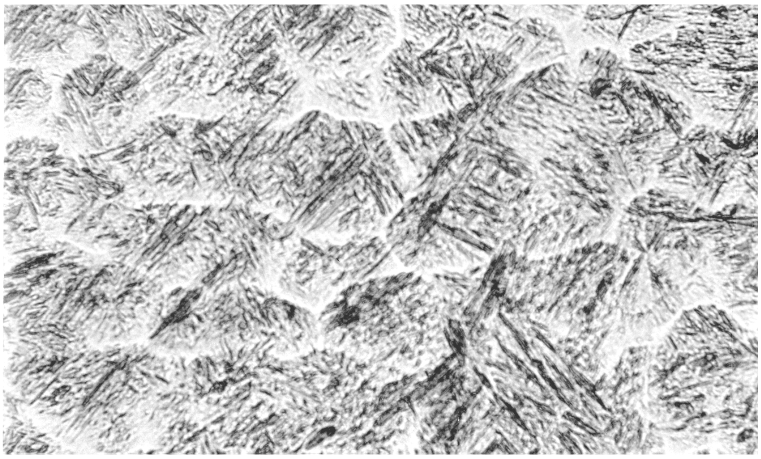
Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type FS Deposit (same electrode as above), ×650, Nital etch

5.3 Fe-M1 Group (low-alloy martensite)

See Table 3.

Table 3 — Fe-M1 Group

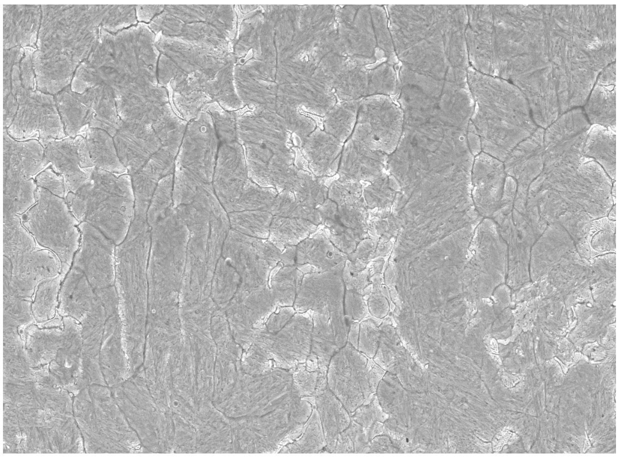
Typical composition: — 0,3 % to 0,8 % C — Up to 6 % alloying elements
Microstructure: Predominantly martensitic
Main characteristics: — Hardness: 450 HB to 600 HB, 45 R_C to 60 R_C, function of mass fraction of C — Generally not machineable as-welded, grinding only. PWHT can soften enough to make deposit easily machineable — Good impact resistance — Excellent metal-to-metal wear resistance — Improved abrasion resistance compared with FS group, function of hardness — Hardness drops if heat treated — Deposits rust — Typical example: 0,5 % C, 5 % Cr, 0,5 % Mo
Applications: Metal-to-metal wear, as in transfer rolls or guides
 Microstructure is predominantly blocky martensite, with white retained austenite around the former grain boundaries. Photomicrograph provided by The Lincoln Electric Company, USA. **Microstructure of Type M1 Deposit, ×650, 2 % Nital**

5.4 Fe-M2 Group (tool-steel martensite)

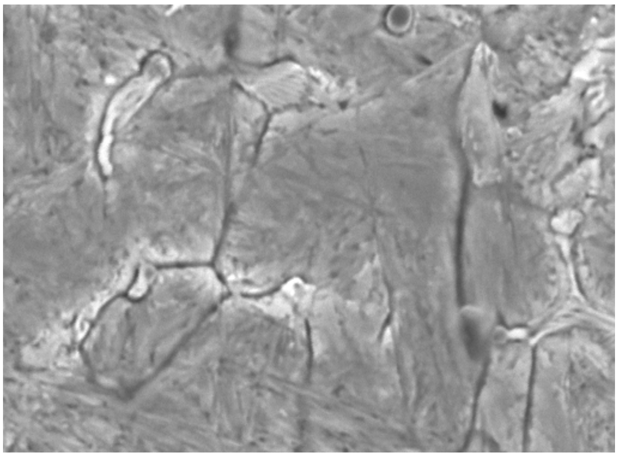
See Table 4.

Table 4 — Fe-M2 Group

Typical composition: — 0,2 % to 1,5 % C — 7 % to 20 % alloying elements, essentially Mo, W, Cr, V
Microstructure: High-alloyed martensite with complex alloy carbides
Main characteristics: — Hardness: Ranging from 45 R_C to 60 R_C (as deposited) — Generally not machineable as-welded, grinding only. PWHT can soften enough to make deposit easily machineable — Fair impact resistance, decreases with increasing mass fraction of carbon — Good abrasion resistance — Maintain or even increase the hardness after heat treatment at temperatures up to 550 °C or higher — Maintain the hardness at high service temperature — Good thermal shock and thermal cycling resistance — Deposits rust — Typical example: 0,7 % C, 3,75 % Cr, 6,0 % Mo, 1,8 % W, 1,1 % V
Applications: Tool steels for hot/cold shears and dies, hot metal-to-metal wear, work rolls in the metals-processing industries



SEM Image, ×1 000

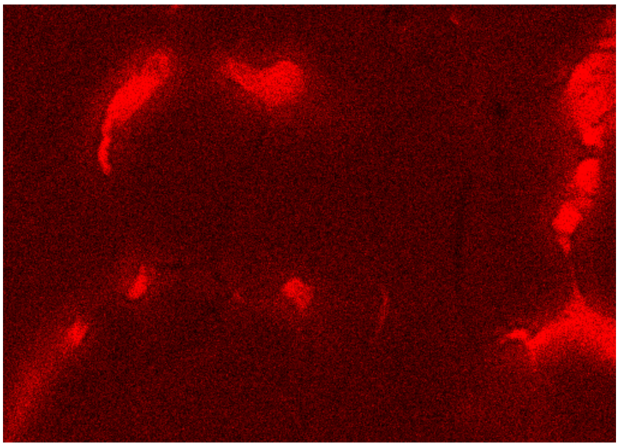


SEM Image, ×5 000

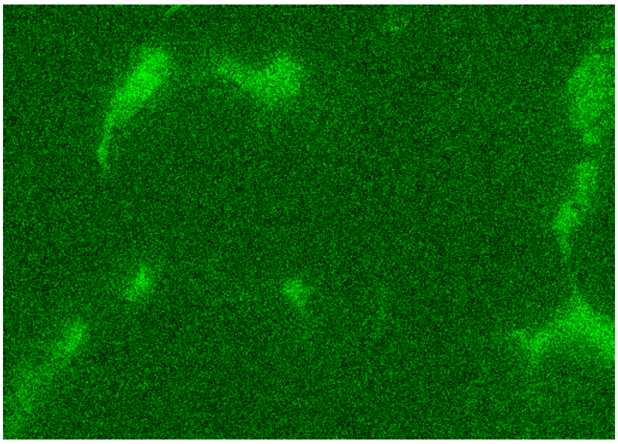
Photomicrographs provided by The Lincoln Electric Company, USA.

(*continued*)

Table 4 (*continued*)



SEM Image, Mo Distribution, ×5 000



SEM Image, V Distribution, ×5 000

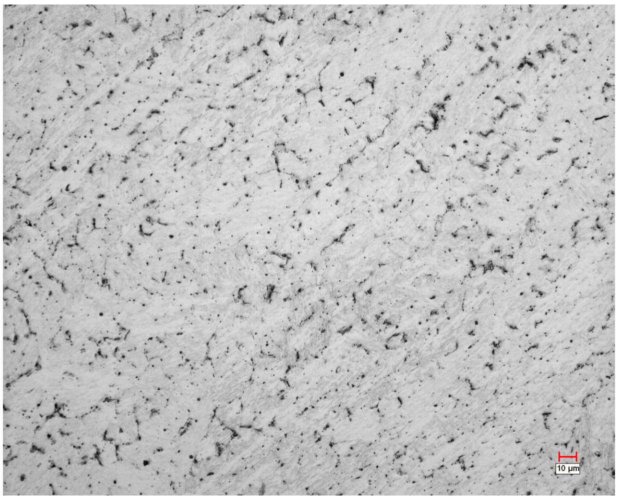
Photomicrographs provided by The Lincoln Electric Company, USA.

5.5 Fe-M3 Group (stainless-steel martensite)

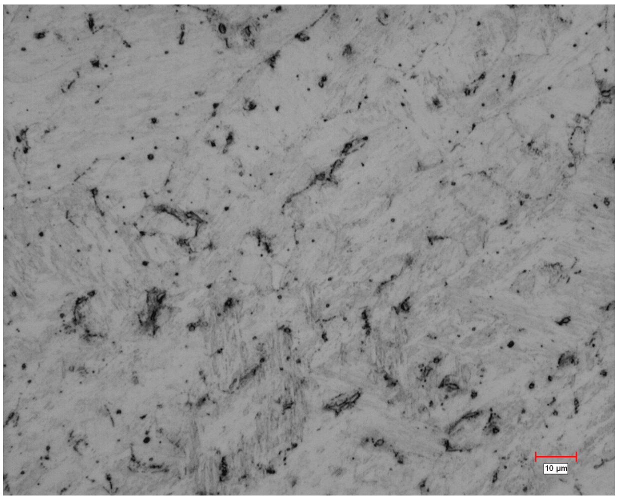
See Table 5.

Table 5 — Fe-M3 Group

Typical composition: — 0,05 % to 0,6 % C — 10 % to 20 % alloying elements, mainly chromium
Microstructure: Essentially martensitic
Main characteristics: — Hardness: ranging from 30 R_C to 55 R_C (as deposited), function of mass fraction of C — Lower carbon deposits are machineable as-welded. Deposits above about 40 R_C usually require PWHT to soften for machining — Fair to good impact resistance — Good corrosion/oxidation resistance, function of the mass fraction of Cr — Good metal-to-metal wear resistance — Low to fair abrasion resistance — Hardness drops if heat treated above about 480 °C — Deposits do not rust — Typical example: 0,17 % C, 1,3 % Mn, 13,6 % Cr, 4,2 % Ni, 0,6 % Mo, 0,6 % Nb, 0,2 % V
Applications: Continuous caster rolls in steel mills



×200



×500

The microstructure is predominantly tempered martensite, with about 1,3 % ferrite (dark etching phase).

Photomicrographs provided by The Lincoln Electric Company, USA.

Microstructure of Type M3 Deposit, Kalling's etch, as-welded condition

5.6 Fe-M4 Group (maraging steel)

See Table 6.

Table 6 — Fe-M4 Group

Typical composition:

- 0,02 % C
- 17 % Ni, 4 % Mo, 9 % Co, 0,5 % Ti + V

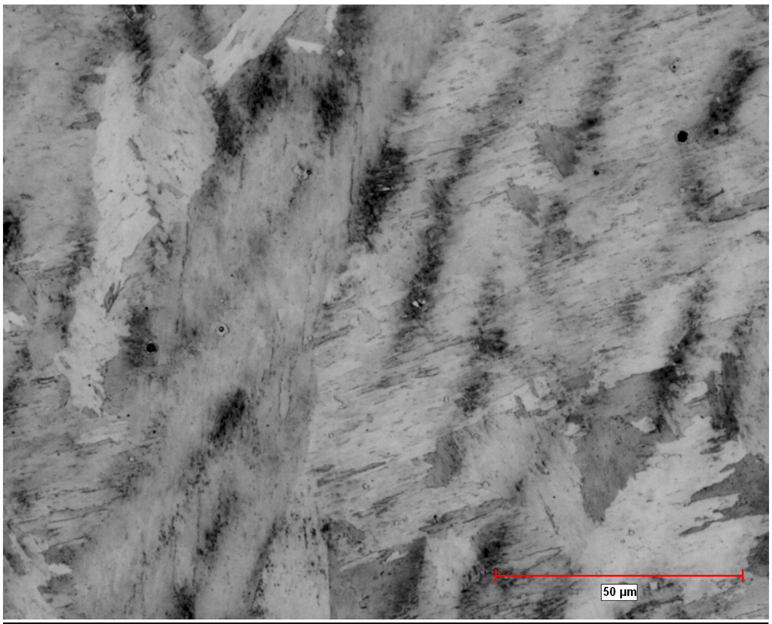
Microstructure:

- low-carbon martensite as-deposited
- martensite with age-hardening precipitates and traces of austenite after PWHT of 450 °C to 480 °C

Main characteristics:

- Hardness: 30 R_C to 40 R_C as deposited
- 50 R_C to 55 R_C after PWHT
- PWHT at 450 °C to 480 °C is essential to developing full hardness
- Readily machineable in the as-deposited condition, much more difficult to machine after PWHT
- High impact resistance
- Low corrosion resistance
- High resistance to thermal shock, but service temperatures limited to 400 °C as higher temperatures over-age the material

Applications: Mill rolls, cutting and stamping dies, die-casting molds for aluminium alloys



Photomicrograph provided by The Lincoln Electric Company USA from a sample provided by Metrode Products Ltd., United Kingdom.

Microstructure of Type M4 Deposit, ×500, Kallings etch

5.7 Fe-MA Group (martensite and austenite)

See Table 7

Table 7 — Fe-MA Group

Typical composition:

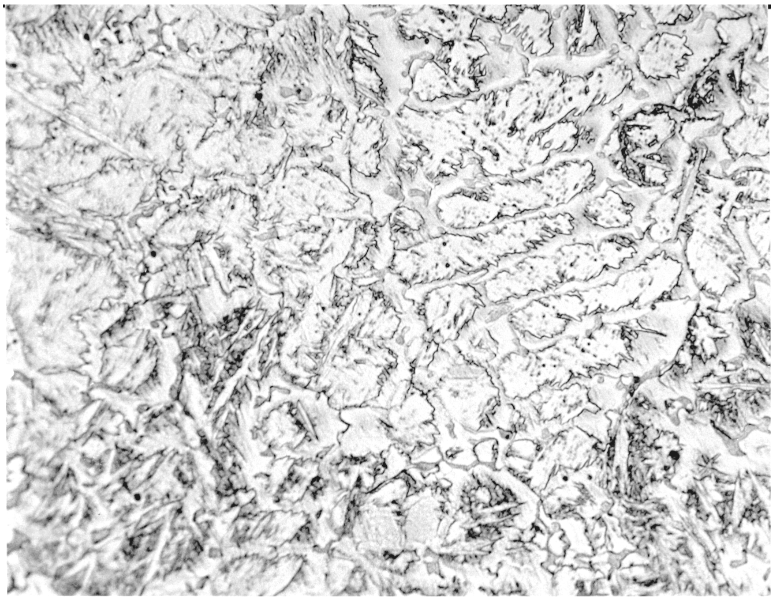
- 0,8 % to 1,5 % C
- 5 % to 15 % alloying elements, mainly Mn, Cr, Si

Microstructure: Martensite and austenite in nearly equal amounts

Main characteristics:

- Hardness: 45 R_C to 60 R_C, work hardens to a limited extent in service
- Generally not machineable as-welded, PWHT tends to reform fresh martensite and does not improve machineability
- Good impact resistance
- Fairly good metal-to-metal wear resistance
- Fairly good abrasion resistance, especially to soft materials such as limestone
- Moderate corrosion resistance
- Tendency to check crack in multiple layers
- Deposits rust
- Typical example: 1 % C, 9 % Cr, 3 % Si alloy

Applications: Agricultural implements in soft soils



Martensite appears as islands that were dendrite cores. Austenite appears as the continuous matrix around the martensite islands.

Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type MA Deposit, ×670, Vilella's etch

5.8 Fe-MK Group (martensite with alloy carbides)

See Table 8.

Table 8 — Fe-MK Group

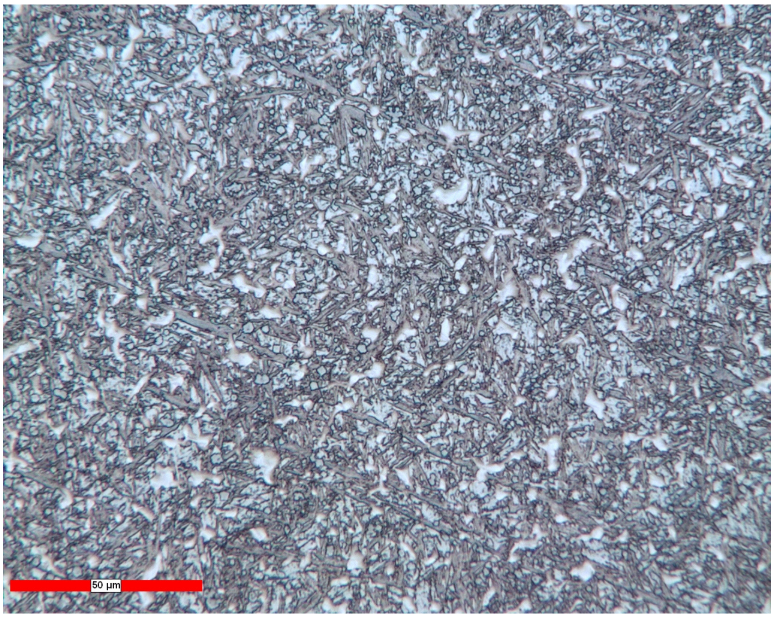
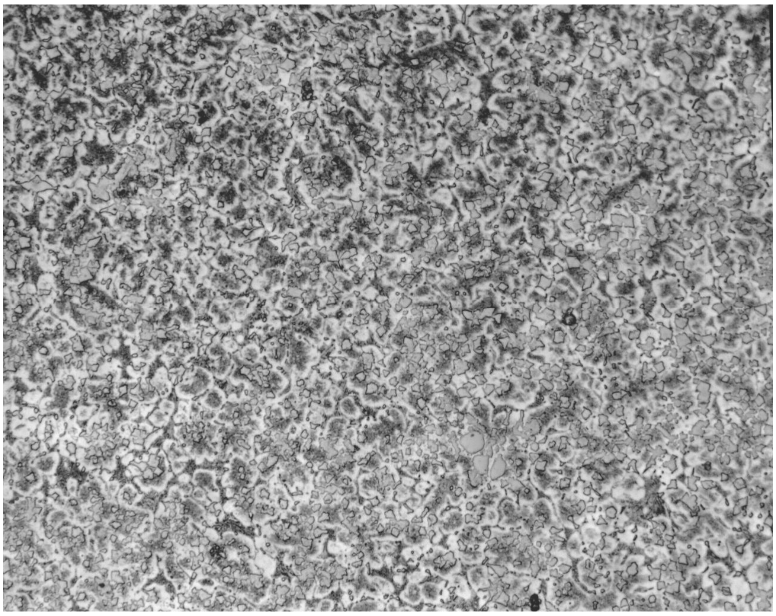
Typical composition: — 1 % to 3 % C — Up to 13 % alloying elements, essentially Cr, Mo, W and a carbide former such as Ti, V, Nb
Microstructure: Medium-alloyed martensite with precipitated carbides
Main characteristics: — Hardness: 50 R_C to 55 R_C — Not machineable as-welded, nor after PWHT; grinding only — Good impact resistance combined with good abrasion resistance, function of amount and type of carbides — Heat treatment softens matrix, but not carbides — Deposits rust — Typical example: Top – 2 % C, 8 % Cr, 1,5 % Mo, 6 % Ti; Bottom – 3 % C, 6 % Cr, 5 % V, 5 % Ti
Applications: Metal-to-metal wear with abrasion, high stress (crushing) abrasion
 Photomicrograph provided by The Stoody Company (a division of Thermadyne Industries). **Microstructure of Type Fe-MK consisting of TiC carbides in a matrix that is predominately martensite** (*continued*)

Table 8 (*continued*)



Photomicrograph provided by ESAB AB, Sweden.

Microstructure of Type Fe-MK consisting of TiC/VC carbides in a matrix that is predominately martensite

5.9 Fe-MEK Group (martensite with eutectic)

See Table 9.

Table 9 — Fe-MEK Group

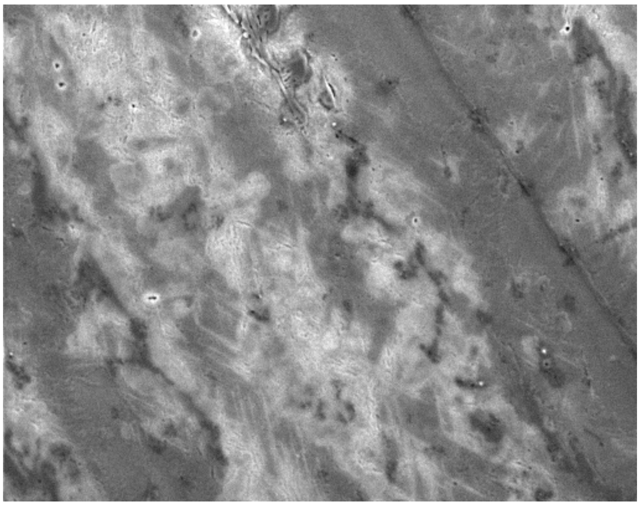
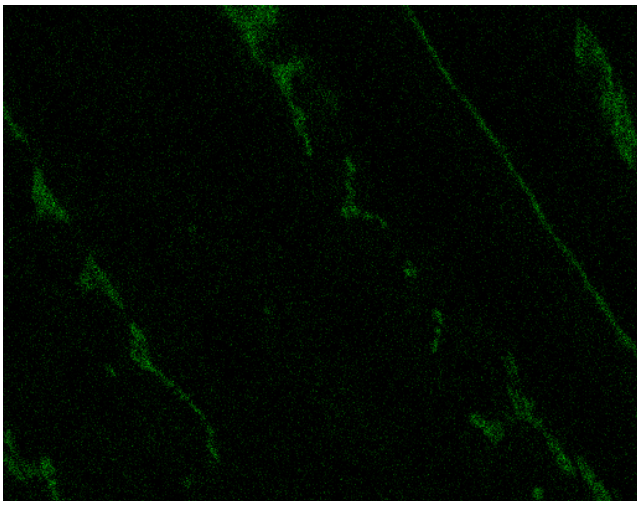
Typical composition: — 2 % to 3 % C — 6 % to 15 % alloying elements, predominantly Cr and Mn
Microstructure: Martensite with austenite-carbide eutectic
Main characteristics: — Hardness: 45 R_C to 60 R_C (as deposited) — Not machineable as-welded, nor after PWHT; grinding only — Good metal-to-metal wear resistance — Fair impact resistance — Moderate abrasion resistance, increases with increasing mass fraction of carbon — Tendency to check crack in multiple layers — Deposits rust — Typical example: 2,2 % C, 7 % Cr
Applications: Cover layer on hammer-mill hammers, metal transfer guides
 SEM photomicrograph, ×1 000 Photomicrograph provided by The Lincoln Electric Company, USA. **Microstructure of Type Fe-MEK consisting of martensite, retained austenite and eutectic carbides** (*continued*)

Table 9 (*continued*)



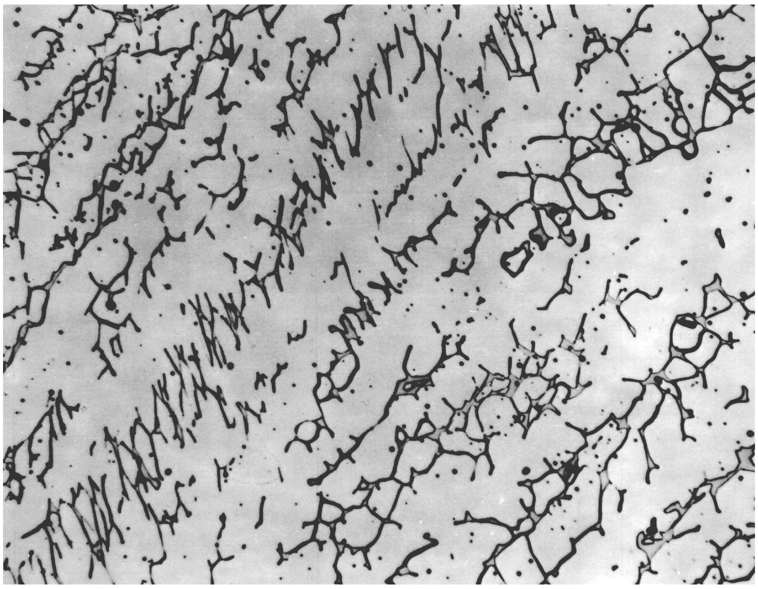
Cr distribution

Photomicrograph provided by The Lincoln Electric Company, USA.

5.10 Fe-A Group (nominally austenitic stainless steel)

See Table 10.

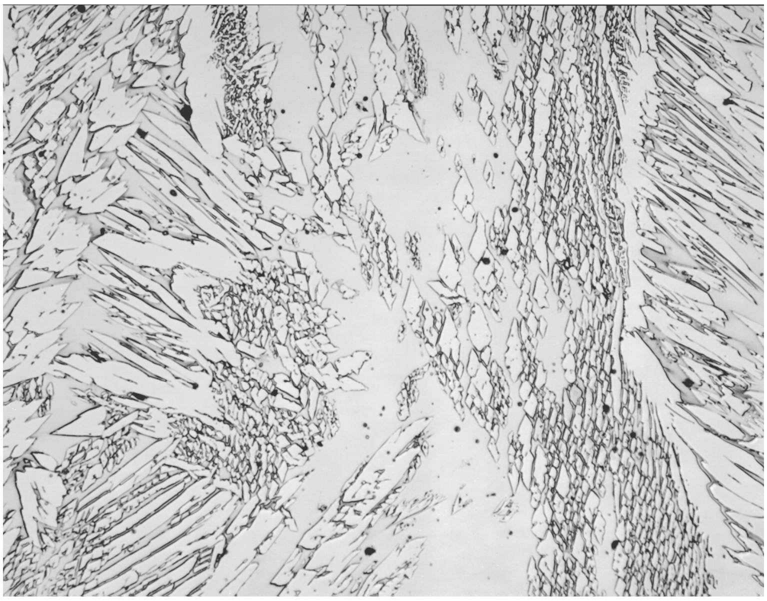
Table 10 — Fe-A Group

Typical composition: — 0,02 % to 0,15 % C — Up to 40 % alloying elements, essentially Cr, Ni, sometimes Mo
Microstructure: Austenite with ferrite below 30 FN
Main characteristics: — Hardness: typically 180 HB to 250 HB, not relevant — Readily machineable with sharp tooling and rigid machinery — High ductility and impact resistance — Excellent corrosion resistance — Fair to good metal-to-metal wear resistance, some tendency to gall under high pressure — Poor abrasion resistance — Work hardenable — Due to ferrite-to-sigma phase transformation, the higher ferrite grades become somewhat embrittled when subjected to heat treatment — Deposits do not rust — Typical examples: 307 (0,1 % C, 4 % Mn, 20 % Cr, 10 % Ni, 1 % Mo), 309 (0,04 % C, 24 % Cr, 13 % Ni), 309 Mo (0,04 % C, 23 % Cr, 13 % Ni, 2,5 % Mo), 310 (0,15 % C, 25 % Cr, 21 % Ni) stainless-steel types
Applications: Buffer layers, joining austenitic manganese plates
 The ferrite is the darker, lacy phase. The austenite is the lighter phase. Some deposits (e.g. 307 or 310) may contain little or no ferrite. Photomicrograph provided by The Lincoln Electric Company, USA. **Microstructure of Type A Deposit, ×500, Kalling's etch**

5.11 Fe-AF Group (ferritic-austenitic stainless steel)

See Table 11.

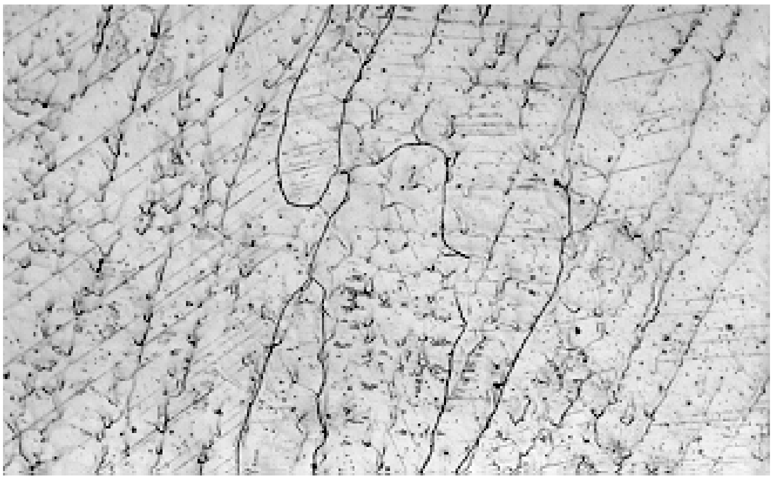
Table 11 — Fe-AF Group

Typical composition: — 0,05 % to 0,15 % C — Up to 40 % alloying elements, essentially Cr, Ni
Microstructure: Austenite with ferrite above 30 FN
Main characteristics: — Hardness: typically 200 HB to 280 HB, not relevant — Readily machineable — High ductility and impact resistance — Excellent corrosion resistance — Fair to good metal-to-metal wear resistance, some tendency to gall under high pressure — Poor abrasion resistance — Work hardenable — Due to ferrite-to-sigma phase transformation, the high-ferrite grades become embrittled when subjected to heat treatment — Deposits do not rust — Typical examples: 312 types of stainless steels, 29 % Cr, 9 % Ni
Applications: Buffer layers, joining austenitic manganese plates, temporary repairs of tool steel and other martensitic pieces
 Lighter austenite plates grow from ferrite grain boundaries, and blocky austenite plates appear within ferrite regions. Photomicrograph provided by The Lincoln Electric Company, USA. **Microstructure of Type AF Deposit, ×500, Murakami's etch**

5.12 Fe-AM Group (austenitic manganese steel)

See Table 12.

Table 12 — Fe-AM Group

Typical composition: — 0,5 % to 1,2 % C — Up to 30 % alloying elements, essentially C, Mn, sometimes up to 8 % Cr, Ni, Mo additions
Microstructure: Austenite (with small amounts of intergranular carbides)
Main characteristics — Hardness: about 300 HB (as deposited), work hardenable up to 550 HB — Machineable only with sharp rigid tooling, with difficulty — Extreme impact resistance — Excellent metal-to-metal wear resistance — Good abrasion resistance, but only in the work-hardened condition — Slow cooling during welding or post-weld heat treatments results in very significant embrittlement of these alloys — Deposits rust — Typical example: 1 % C, 14 % Mn
Applications: Rock crushers, hammer-mill hammers, rail frogs
 Microstructure is almost all austenite, with only a few scattered carbides and inclusions. Photomicrograph provided by The Lincoln Electric Company, USA. **Microstructure of Type AM Deposit, ×260, 5 % Nital + 15 % HCl etch**

5.13 Fe-AMC Group (austenitic chromium-manganese steel)

See Table 13.

Table 13 — Fe-AMC Group

Typical composition:

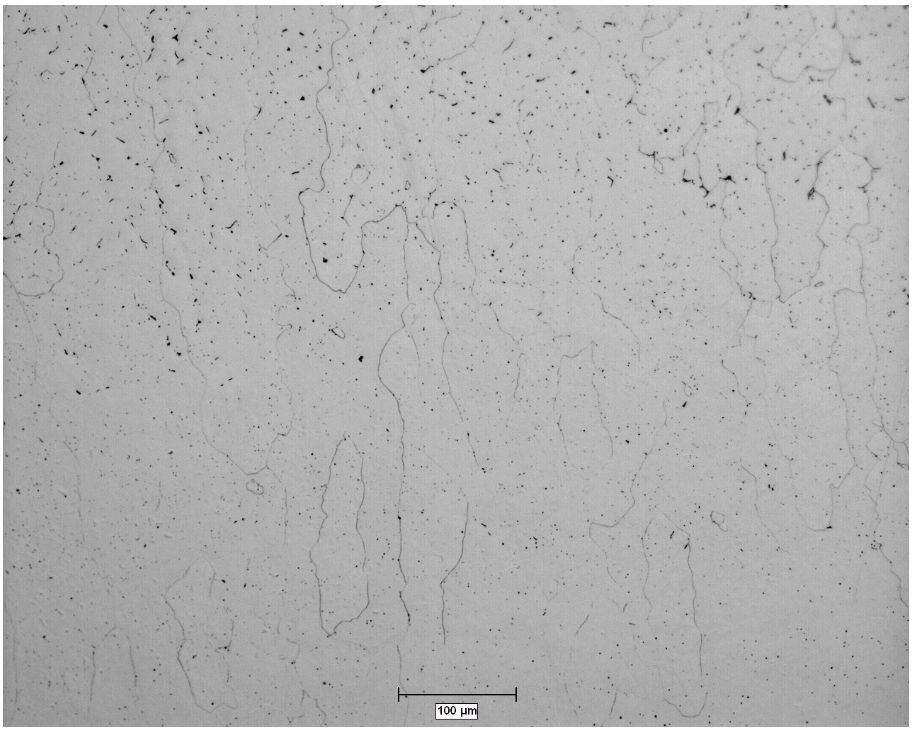
- 0,3 % to 0,5 % C
- 25 % to 40 % alloying elements, essentially Cr and Mn in nearly equal amounts

Microstructure: Austenite

Main characteristics:

- Hardness: about 300 HB (as deposited), work hardenable up to 550 HB
- Machineable only with sharp and rigid tooling, with difficulty
- Extreme impact resistance
- Excellent metal-to-metal wear resistance
- Very good abrasion resistance, but only in the work-hardened condition
- Slow cooling during welding or post-weld heat treatments results in some embrittlement of these alloys, but is much less susceptible to thermal embrittlement than the AM Group
- Deposits do not rust
- Typical example: 0,4 % C, 15 % Mn, 15 % Cr

Applications: Joining austenitic manganese-base metals, buffer and build-up layers, rock crushers, hammer-mill hammers, rail frogs



Microstructure is almost all austenite, with only a few scattered carbides and inclusions.

Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type AMC Deposit, ×100, 20 % aqua regia etch

5.14 Fe-AK Group (austenitic manganese steel containing alloy carbides)

See Table 14.

Table 14 — Fe-AK Group

Typical composition:

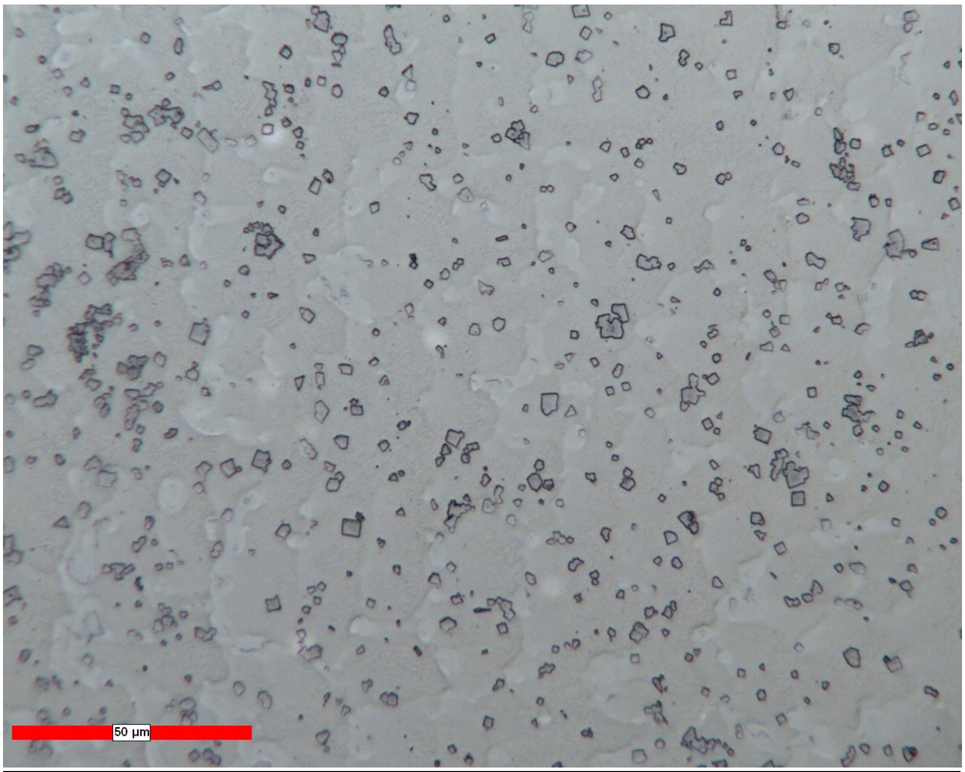
- 1 % to 2 % C
- 15 % to 25 % alloy, mainly manganese with Ti or Nb as a strong carbide former

Microstructure: Austenite with dispersed alloy carbides

Main characteristics:

- Hardness: 30 R_C to 40 R_C (as deposited), work hardens rapidly
- Not machineable as welded, nor after PWHT
- Excellent impact resistance
- Very good abrasion resistance
- Good metal-to-metal wear resistance
- Slow cooling during welding or post-weld heat treatments results in very significant embrittlement of these alloys
- Deposits rust
- Typical example: 2 % C, 15 % Mn, 3,5 % Cr, 3,5 % Ti

Applications: Severe impact with abrasion-hammer-mill hammers, rock crushers



×500, Nital etch

Photomicrograph provided by The Stoody Company (a division of Thermadyne Industries).

5.15 Fe-PAE Group (primary austenite with eutectic)

See Table 15.

Table 15 — Fe-PAE Group

Typical composition:

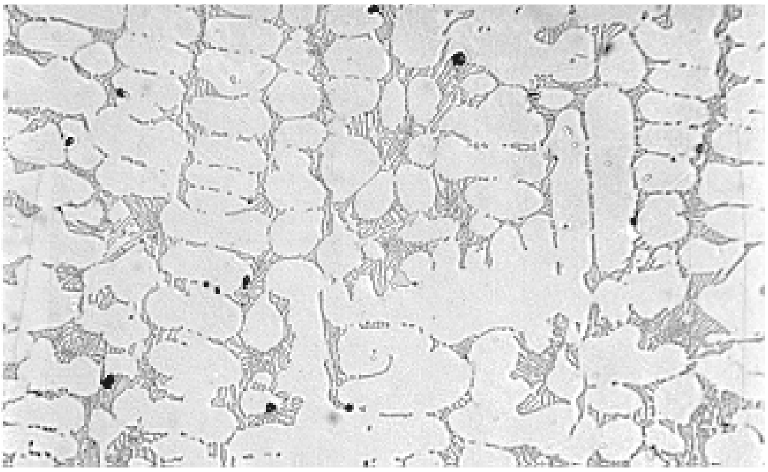
- 2 % to 3 % C
- 15 % to 35 % alloy elements, mainly Cr but often some Mo

Microstructure: Primary austenite with austenite-carbide eutectic, carbides are mainly of the $M_{23}C_6$ type

Main characteristics:

- Hardness: 40 R_C to 55 R_C (as deposited), some work hardening in softer alloys with a lower C content
- Not machineable, grinding only
- Fair impact resistance, decreases with increasing mass fraction of carbon
- Good abrasion resistance, increases with increasing mass fraction of carbon
- Not softened by PWHT
- Alloys with a lower C and higher Cr content have some corrosion resistance due to significant amounts of Cr remaining in solid solution after all carbides are formed, others rust
- Multi-layer deposits in stringer beads tend to check crack at intervals of 25 mm to 50 mm
- Deposits rust
- Typical example: 2,5 % C, 30 % Cr

Applications: Abrasion with significant impact-cap layers on hammer-mill hammers, bucket teeth.



Large light shapes are primary austenite. The mottled structure consists of eutectic mix of $M_{23}C_6$ carbides (darker) with austenite (lighter).

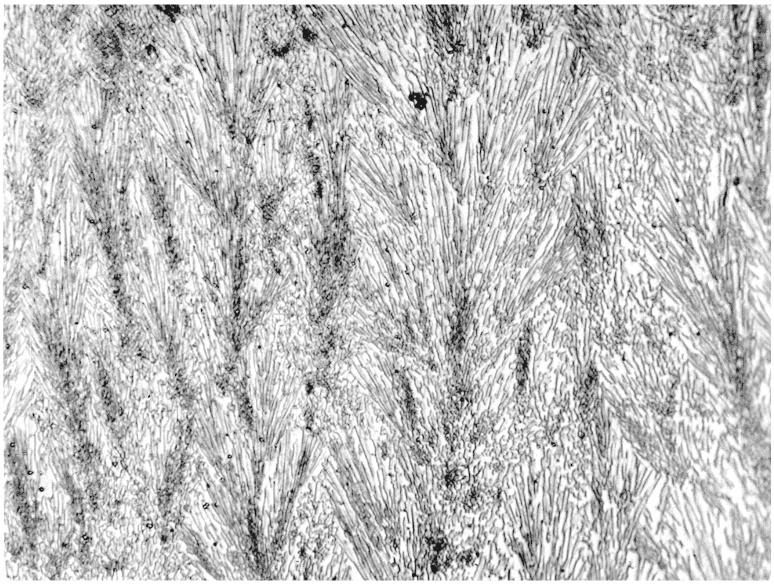
Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type PAE Deposit, ×650, 5 % Nital etch

5.16 Fe-NE Group (near eutectic)

See Table 16.

Table 16 — Fe-NE Group

<table>
<tr><td>Typical composition:
— 3 % to 4 % C
— 20 % to 35 % alloy, mainly Cr but often with some Mo</td></tr>
<tr><td>Microstructure: Near-eutectic mix of austenite and carbides (mainly $M_{23}C_6$ type); alloys with a lower C content may have a small amount of primary austenite, while alloys with a higher C content may have a small amount of primary carbides, but properties are dominated by the eutectic</td></tr>
<tr><td>Main characteristics:
— Hardness: 53 R_C to 58 R_C (as deposited), alloys do not work harden and do not soften appreciably by PWHT
— Not machineable as-welded, nor after PWHT; grinding only
— Fair impact resistance
— Good abrasion resistance
— Multi-layer deposits in stringer beads tend to check crack at intervals of 20 mm to 30 mm
— Deposits rust
— Typical example: 3,5 % C, 25 % Cr</td></tr>
<tr><td>Applications: Abrasion with moderate impact: bucket lips and teeth, earth-moving blades</td></tr>
<tr><td>
Lamellar structure consists of a eutectic mix of dark $M_{23}C_6$ carbides in lighter austenite.
Photomicrograph provided by The Lincoln Electric Company, USA
Microstructure of Type NE Deposit, ×670, Vilella's etch</td></tr>
</table>

5.17 Fe-PKE Group (primary carbides with eutectic)

See Table 17.

Table 17 — Fe-PKE Group

Typical composition:

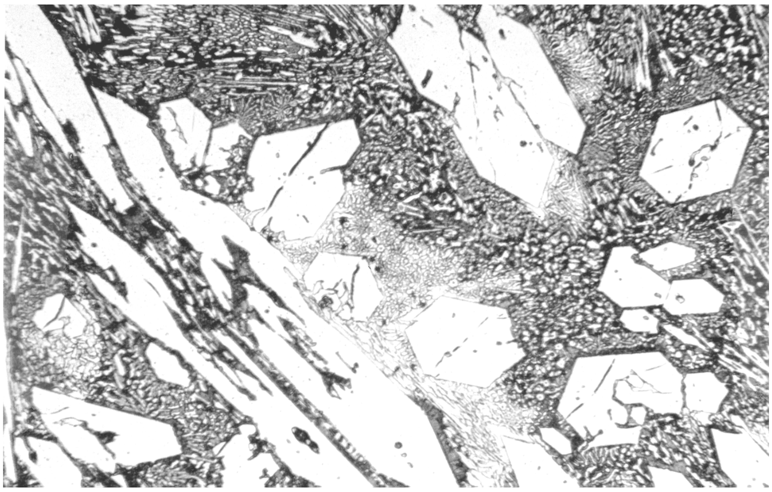
- More than 4 % C
- 20 % to 35 % alloy, mainly Cr

Microstructure: Primary carbides (Cr_7C_3 type, appearing as large hexagonal rods) in a matrix of eutectic austenite-carbide (mainly $M_{23}C_6$ type)

Main characteristics:

- Hardness: 58 R_C to 65 R_C, does not work harden, does not soften in PWHT
- Not machineable, grinding only
- Low impact resistance
- Excellent abrasion resistance
- Multi-layer deposits in stringer beads tend to check crack at intervals of 10 mm to 20 mm
- Deposits rust
- Typical example: 4,5 % C, 25 % Cr

Applications: Severe abrasion: coal crusher rolls, ore chutes



Large white shapes are M_7C_3 carbides; mottled dark structure consists of austenite plus $M_{23}C_6$ carbide eutectic. At a higher magnification, the austenite-carbide eutectic will appear exactly as it does in the Type PAE and NE deposits.

Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type PKE Deposit, ×260, Vilella's etch

5.18 Fe-KKA Group (primary carbides, alloy carbides and eutectic)

See Table 18.

Table 18 — Fe-KKA Group

Typical composition:

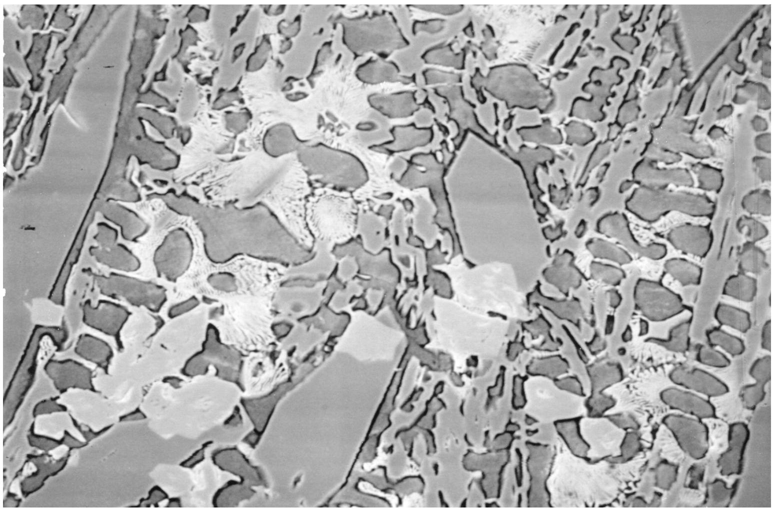
- More than 5 % C
- 25 % to 40 % alloy, mainly Cr but also at least 5 % of a strong carbide former (Ti, Nb, V)

Microstructure: Large primary carbides (Cr_7C_3 type) and dispersed harder (but smaller) alloy carbides (TiC, NbC, VC type) in a eutectic austenite/carbide ($M_{23}C_6$ type) matrix

Main characteristics:

- Hardness: 58 R_C to 70 R_C (as deposited), not softened by PWHT, does not work harden
- Not machineable, grinding only
- Excellent abrasion resistance (both low stress and high stress), abrasion resistance retained up to 650 °C
- Low impact resistance
- Multi-layer deposits in stringer beads tend to check crack at intervals of 5 mm to 15 mm
- Deposits rust
- Typical example: 5,5 % C, 20 % Cr, 6 % Mo, 6 % Nb

Applications: Severe abrasion, often at high temperatures, cement clinker crushers



Darker angular particles are Cr_7C_3 primary carbides (the same as in Type PKE deposit); lighter particles are complex Mo-Nb carbides (mostly formed from eutectic); spaces between carbides consist of austenite (formed from eutectic).

Photomicrograph provided by The Lincoln Electric Company, USA.

Microstructure of Type KKA Deposit, ×1 040, Vilella's etch, SEM image

6 Summary of the designators for non-ferrous hardfacing deposit types

Most of the currently known non-ferrous hardfacing alloys fall into one of thirteen microstructural categories. These types of microstructures are listed in Table 19, which also gives the proposed designations. For convenience, only the E (electrode) form is shown, but it is understood that T (tubular-cored electrode), S (solid wire or rod) or P (powder) may be substituted for E.

Table 19 — Non-ferrous-base hardfacing deposit types

Hardfacing deposit designation	Microstructure type
E-H-Co-CS	Cobalt solid-solution alloy
E-H-Co-PC	Primary cobalt solid-solution alloy with cobalt alloy/carbide eutectic
E-H-Co-NE	Near-eutectic mix of carbides and cobalt solid-solution alloy
E-H-Co-PKE	Primary carbides with cobalt alloy/carbide eutectic
E-H-Co-LP	Cobalt solid-solution alloy with Laves-phase intermetallic compounds
E-H-Ni-NS	Nickel solid-solution alloy
E-H-Ni-B	Primary nickel alloy solid solution with nickel alloy/boride eutectic
E-H-Ni-CB	Primary nickel alloy solid solution with nickel alloy/chrome boride eutectic
E-H-Ni-LP	Nickel solid-solution alloy with Laves-phase intermetallic compounds
E-H-Cu-BS	Solid-solution bronzes
E-H-Cu-BT	Two-phase bronzes
E-H-W-Fe	Approximately 40 % to 60 % (by mass) tungsten carbide in an alloy steel matrix
E-H-W-Ni	Approximately 40 % to 60 % (by mass) tungsten carbide in a nickel alloy matrix

7 Description of the alloys belonging to the different non-ferrous microstructure groups and microstructural illustrations

7.1 Co-CS Group (cobalt solid-solution alloy)

See Table 20.

Table 20 — Co-CS Group

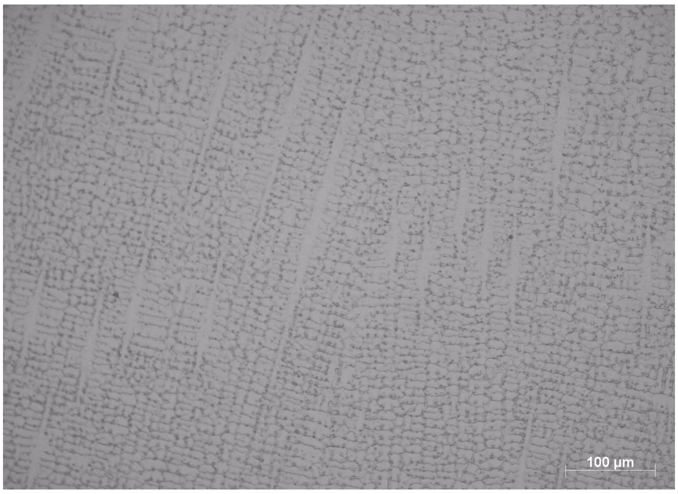
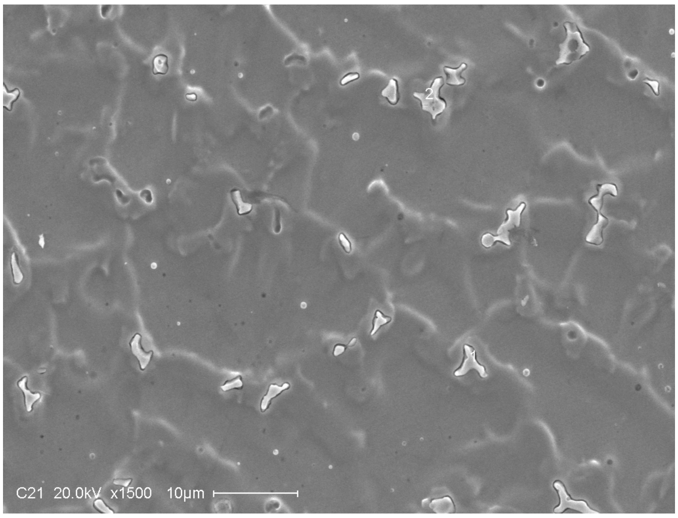
Typical composition: — 0,15 % to 0,40 % C — Approximately 26 % Cr, 3 % Ni, 5 % Mo, balance Co
Microstructure: Predominately cobalt alloy solid solution with scattered carbides
Main characteristics: — Hardness (as deposited): 20 R_C to 30 R_C — Seldom heat treated, little hardness change occurs in heat treatment — Machineable in the as-welded condition, but with difficulty, due to rapid work-hardening — Excellent impact resistance — Exceptional metal-to-metal wear resistance, especially to galling — Exceptional cavitation erosion resistance — High corrosion resistance — High resistance to thermal shock, oxidizing and reducing atmospheres. Strength and ductility retained up to 850 °C
Applications: Valve faces and valve seats in aqueous corrosive environments and in hot gas environments
 5 % HCl electrolytic etch Optical, ×200 Photomicrograph provided by The Lincoln Electric Company, USA. (*continued*)

Table 20 (*continued*)



The particles in the cell boundaries are identified as carbides rich in Cr and Mo.

SEM, ×1 500

Photomicrograph provided by The Lincoln Electric Company, USA.

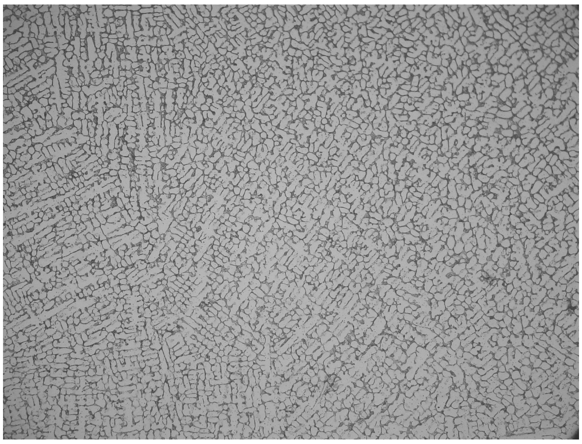
7.2 Co-PC Group (primary cobalt solid-solution alloy with cobalt alloy/carbide eutectic)

See Table 21.

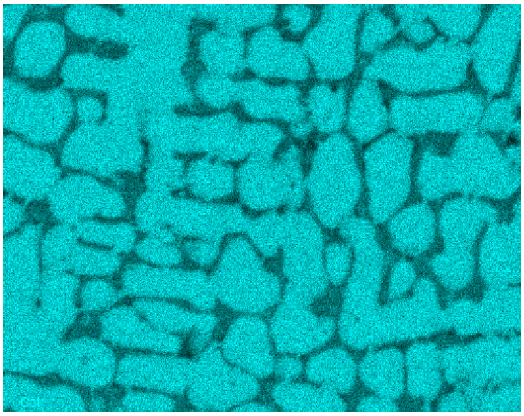
Table 21 — Co-PC Group

Typical composition: — 0,7 % to 1,7 % C — Approximately 28 % Cr, 4 % W, 1 % Ni, 2 % Fe, balance Co
Microstructure: Primary cobalt solid solution with eutectic carbides
Main characteristics: — Hardness (as deposited): 40 R_C to 45 R_C — Seldom heat treated, little hardness change occurs in heat treatment — Very difficult to machine using carbide tools; grinding is preferred — Good impact resistance and abrasion resistance — Good metal-to-metal wear resistance — High corrosion resistance — High resistance to thermal shock, oxidizing and reducing atmospheres
Applications: Valve seats and valve faces in internal combustion engines and other hot-fluid streams containing particulates
The optical image below cannot resolve the eutectic, but the scanning electron microscope (SEM) back-scattered electron image can. Note that cobalt is shown by the SEM to be concentrated in the dendrite cores, while chromium and tungsten are shown to be concentrated in the inter-dendritic eutectic regions. (*continued*)

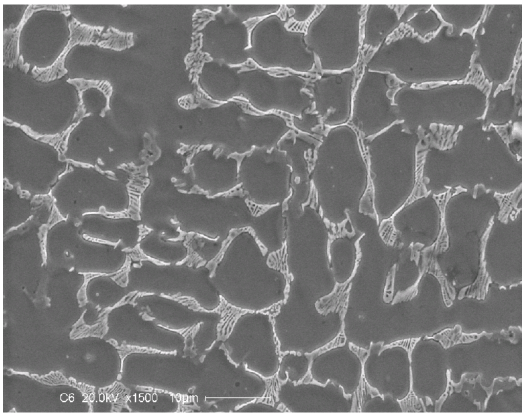
Table 21 (*continued*)



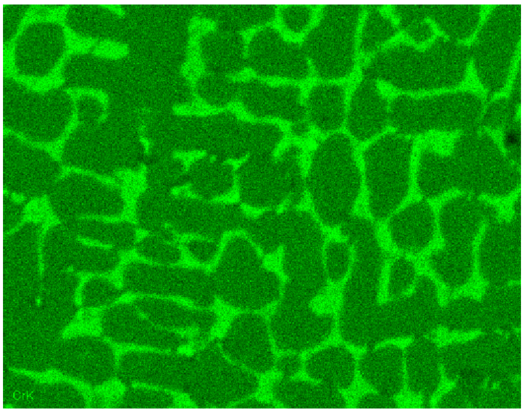
Optical image ×200



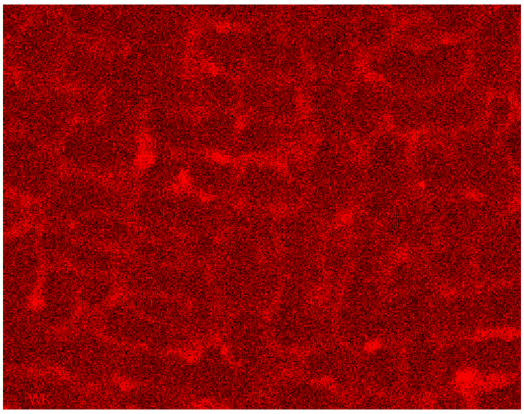
Co map



Back-scattered electron image, ×1 500



Cr map



W map

Photomicrographs provided by The Lincoln Electric Company.

7.3 Co-NE Group (near-eutectic mix of carbides and cobalt solid-solution alloy)

See Table 22.

Table 22 — Co-NE Group

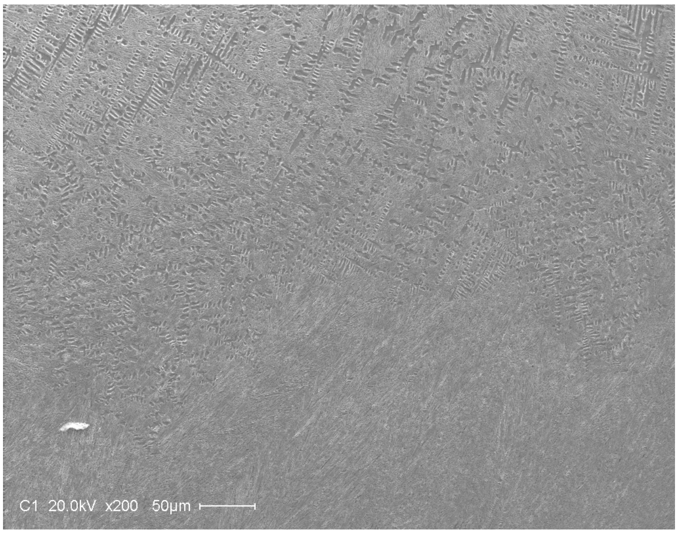
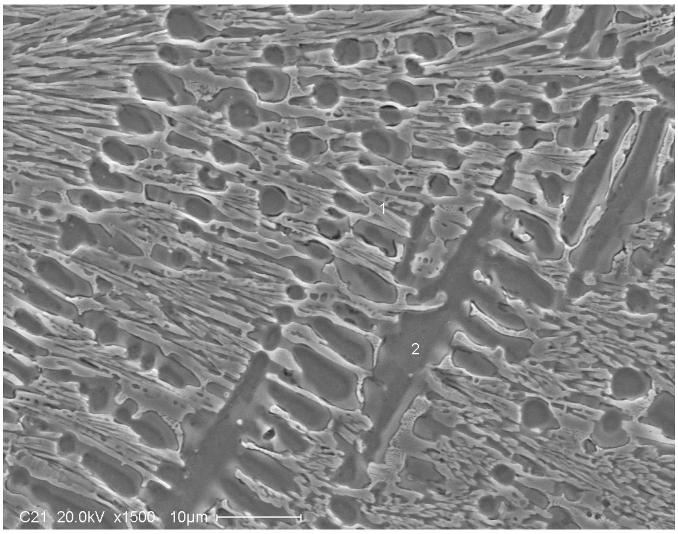
Typical composition: — 1,8 % to 2,2 % C — Approximately 28 % Cr, 12 % W, 1 % Ni, 2 % Fe, balance Co
Microstructure: Near-eutectic mix of carbides and cobalt alloy solid solution, only traces of primary cobalt or primary carbides
Main characteristics: — Hardness (as deposited): 45 R_C to 50 R_C — Difficult to deposit without cracking, even with preheating at 300 °C to 400 °C. Seldom post-weld heat treated, little hardness change occurs in heat treatment — Not machineable, grinding only — Moderate impact resistance — High abrasion resistance — Moderate corrosion resistance — Retains abrasion resistance at high temperatures
Applications: High-temperature mixers, sliding components in furnaces
 5 % HCl electrolytic etch Optical, ×200 Photomicrograph provided by The Lincoln Electric Company, USA. (*continued*)

Table 22 (*continued*)



SEM, ×1 500

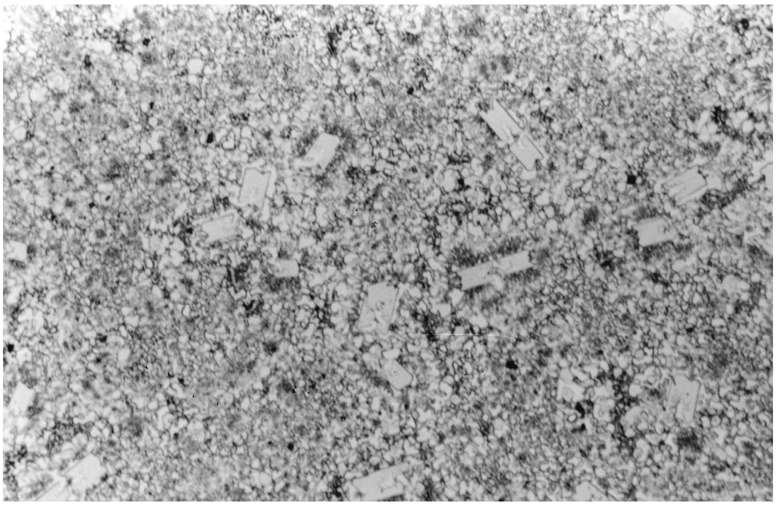
Scattered primary cobalt solid-solution dendrites (2) appear among the extensive cobalt plus carbide eutectic (1).

Photomicrograph provided by The Lincoln Electric Company, USA.

7.4 Co-PKE Group (primary carbides with eutectic)

See Table 23.

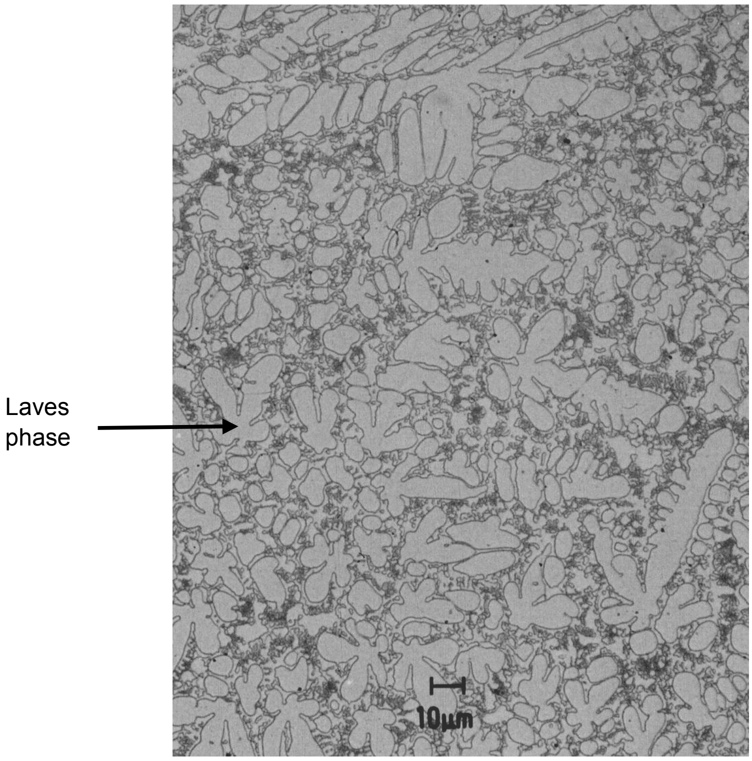
Table 23 — Co-PKE Group

Typical composition: — 2,5 % C — 30 % Cr, 12 % W, 4 % Fe
Microstructure: Primary M_7C_3 type carbides in a matrix of eutectic carbides and solid-solution cobalt alloy
Main characteristics: — Hardness (as deposited): 50 R_C to 55 R_C — Very difficult to deposit without cracking, even with very high preheating. Seldom heat treated, little hardness change occurs in heat treatment — Not machineable, grinding only — Low impact resistance — Exceptional abrasion resistance at high temperatures (1 000 °C and upwards) — Moderate corrosion resistance — Good resistance to oxidizing environments
Applications: High-temperature abrasion resistance, such as catalyst slide trays, furnace chains
 Optical, ×400 Photomicrograph provided by Tokuden Co., Ltd., Japan.

7.5 Co-LP Group (cobalt solid-solution alloy with Laves phase particles)

See Table 24.

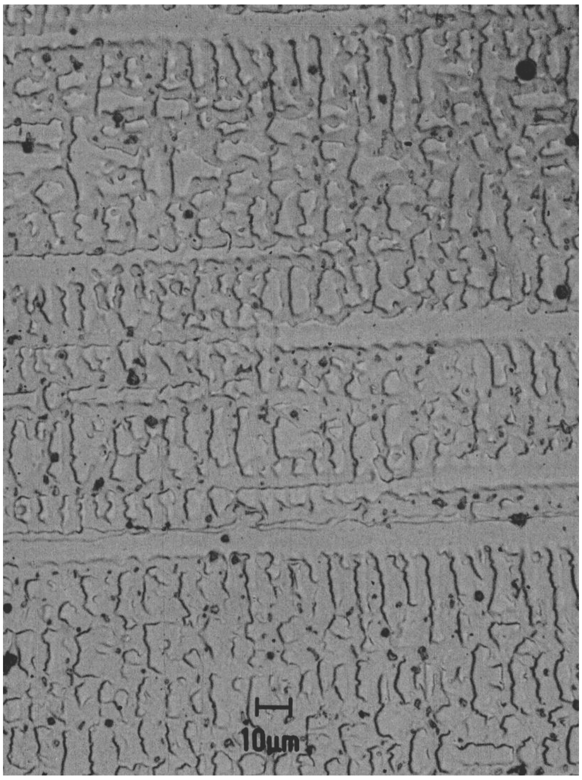
Table 24 — Co-LP Group

Typical composition: 0,08 % C max., 25 % to 35 % Mo, 8 % to 18 % Cr, 2 % to 4 % Si, balance Co
Microstructure: Cobalt alloy solid solution containing Laves-phase particles (Mo-Cr-Si intermetallic compounds)
Main characteristics: — Hardness (as deposited): 40 R_C to 45 R_C — Heat treatment can be used to precipitate additional Laves phase, increase the hardness to over 50 R_C — Machineable with carbide tools — Good impact resistance — Exceptional metal-to-metal wear resistance — Moderate abrasion resistance — Moderate corrosion resistance — Typical example: 0,02 % C, 3,6 % Si, 0,3 % Ni, 17 % Cr, 30 % Mo, 0,7 % Fe, balance Co
Applications: Unlubricated bearing surfaces, valve seats and valve faces
 Photomicrograph provided by Nippon Welding Rod Co., Ltd, Japan. **Microstructure of Type Co-LP, ×400**

7.6 Ni-NS Group (nickel alloy solid solution)

See Table 25.

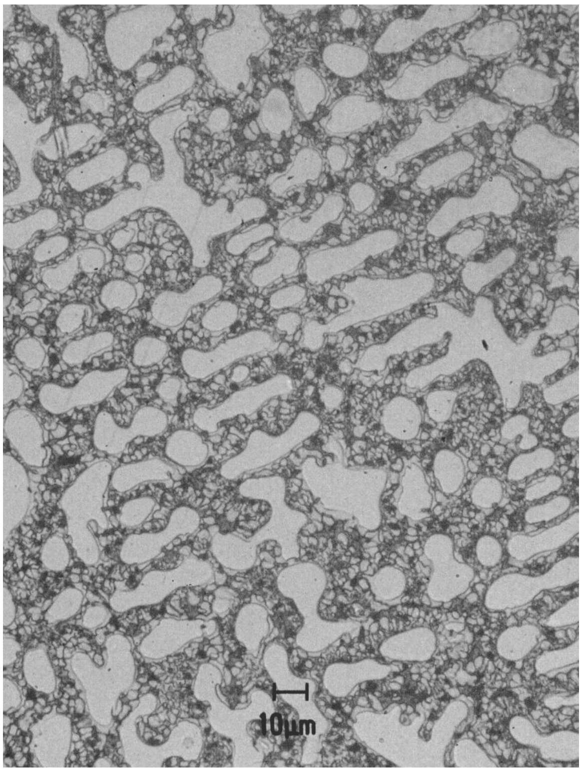
Table 25 — Ni-NS Group

Typical composition: 0,1 % C, 17 % Cr, 17 % Mo, 4,5 % W, 5,5 % Fe, balance Ni
Microstructure: Primarily nickel-base alloy solid solution; some intermetallic compound precipitation is possible after prolonged high-temperature exposure
Main characteristics: — Hardness (as deposited): 90 R_B — Seldom heat treated, may soften in heat treatment — Machineable in the as-welded condition — Excellent impact resistance — Limited metal-to-metal wear resistance — Low abrasion resistance — High corrosion resistance — High resistance to thermal shock
Applications: Forging dies, hot extrusion dies
 Photomicrograph provided by Nippon Welding Rod Co., Ltd., Japan. **Microstructure of Type Ni-NS**

7.7 Ni-B Group (nickel borides)

See Table 26.

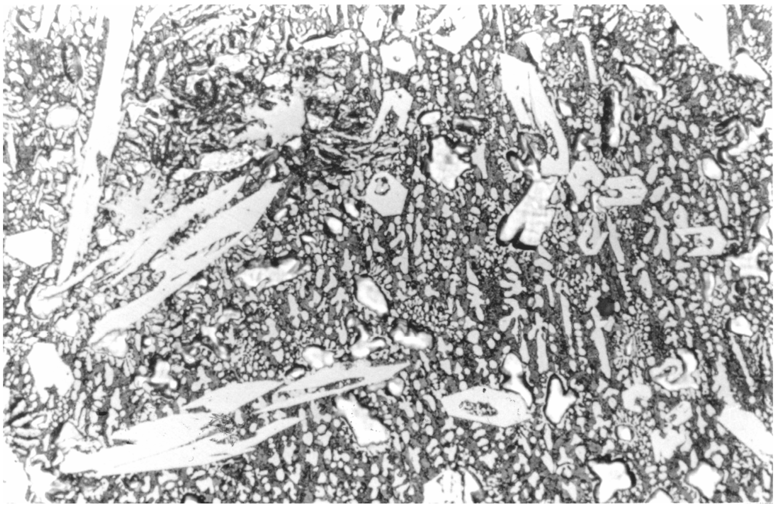
Table 26 — Ni-B Group

Typical composition: 0,2 % to 0,5 % C, 1,5 % to 1,8 % B, 1 % to 8 % Cr, 2 % to 4 % Si, up to 2 % Fe, balance Ni
Main characteristics: — Hardness (as deposited): 20 R_C to 40 R_C — Seldom heat treated, little hardness change with heat treatment — Machineable with carbide tools (difficult), grinding preferred — Moderate impact resistance — Good abrasion resistance — Moderate corrosion resistance
Applications: Self-fluxing, low-melting hardfacing alloy for abrasion resistance, often applied in thin single layers
 Composition of example: 0,25 % C, 3,5 % Si, 7,5 % Cr, 2,5 % Fe, 1,6 % B, balance Ni. Primary nickel alloy solid-solution dendrites surrounded by nickel/chromium/boride eutectic. Photomicrograph provided by Nippon Welding Rod Co., Ltd., Japan. **Microstructure of Type Ni-B**

7.8 Ni-CB Group (chromium borides in nickel alloy/boride eutectic)

See Table 27.

Table 27 — Ni-CB Group

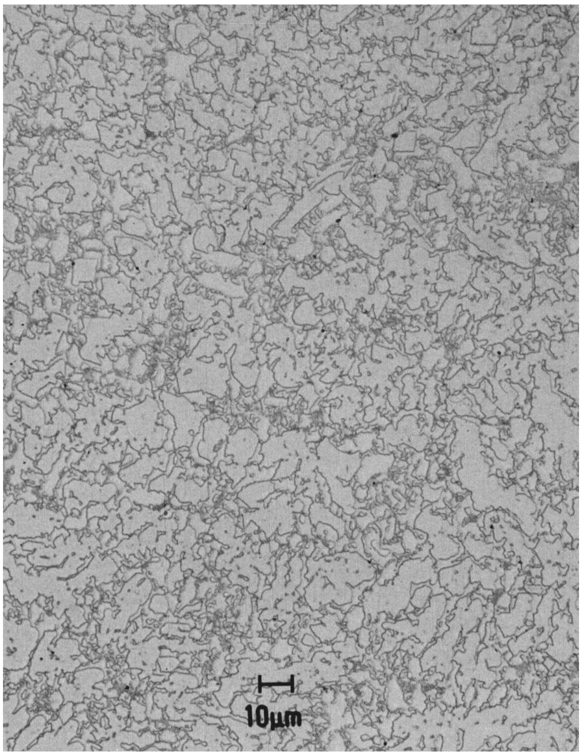
Typical composition: 0,5 % C, 2,5 % to 3,5 % B, 11 % to 15 % Cr, 3,5 % Fe, 4 % Si, balance Ni
Microstructure: Primary chromium borides in nickel alloy/boride eutectic
Main characteristics: — Hardness (as deposited): 50 R_C to 60 R_C — Seldom heat treated, little hardness change in heat treatment — Not machineable, grinding only — Moderate impact resistance — Exceptional abrasion resistance — Moderate corrosion resistance
Applications: Severe abrasion resistance in aqueous media
 Hexagonal chromium boride rods in a nickel-chromium-boron eutectic matrix. Composition: 0,7 % C, 4,3 % Si, 15,0 % Cr, 2,7 % Fe, 3,0 % B, balance Ni. Photomicrograph provided by Tukoden Co., Ltd., Japan. **Microstructure of Type Ni-CB, ×400**

7.9 Ni-LP Group (nickel-base alloy solid solution with Laves-phase particles)

See Table 28.

Table 28 — Ni-LP Group

Typical composition: 0,05 % C, 32 % Mo, 16 % Cr, 3,5 % Si, balance Ni
Microstructure: Nickel alloy solid solution with massive Laves-phase particles
Main characteristics: — Hardness (as deposited): 40 R_C to 50 R_C, can harden a few more R_C points during heat treatment if additional Laves-phase precipitates — Very difficult to machine, grinding preferred — Moderate impact resistance — Exceptional metal-to-metal wear resistance, especially to galling, in unlubricated conditions — Good corrosion resistance — Retains wear resistance over a wide temperature range
Applications: Valves, piston rings, wear pads and seals



Photomicrograph provided by Nippon Welding Rod Co., Ltd., Japan.

Microstructure of Type Ni-LP

7.10 Cu-BS Group (solid-solution bronzes)

See Table 29.

Table 29 — Cu-BS Group

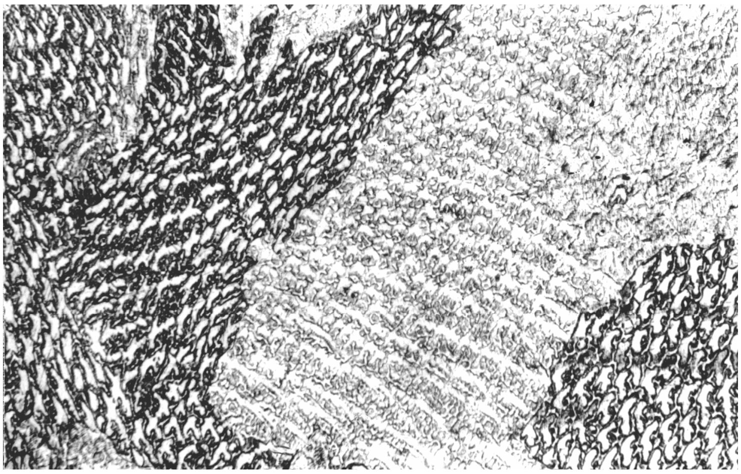
Typical composition: Up to 4 % Si or up to 2 % Sn, balance mainly copper, may contain some phosphorus

Microstructure: Copper-rich solid-solution alloy hardened by solute elements

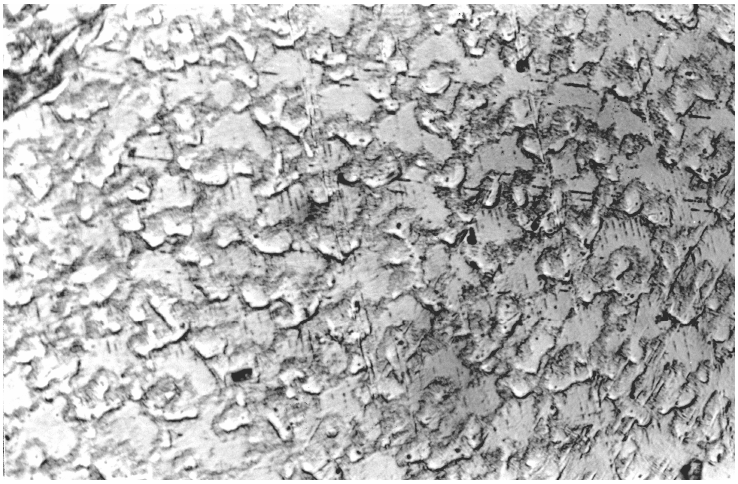
Main characteristics:

- Hardness (as deposited): 80 R_B to 90 R_B
- Seldom heat treated, little effect
- Readily machineable
- High impact resistance
- Very good corrosion resistance in fresh water and seawater

Applications: Bearings, pump and valve parts, corrosion-resistant overlays



×100



×400

Composition: 3,48 % Si, 0,88 % Mn, balance Cu.

Photomicrographs provided by Tokuden Co., Ltd., Japan.

Microstructure of Type Cu-BS

7.11 Cu-BT Group (two-phase bronzes)

See Table 30.

Table 30 — Cu-BT Group

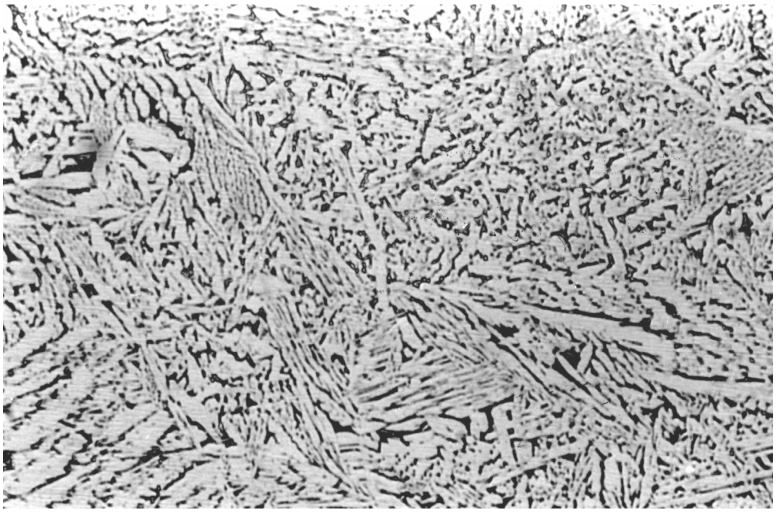
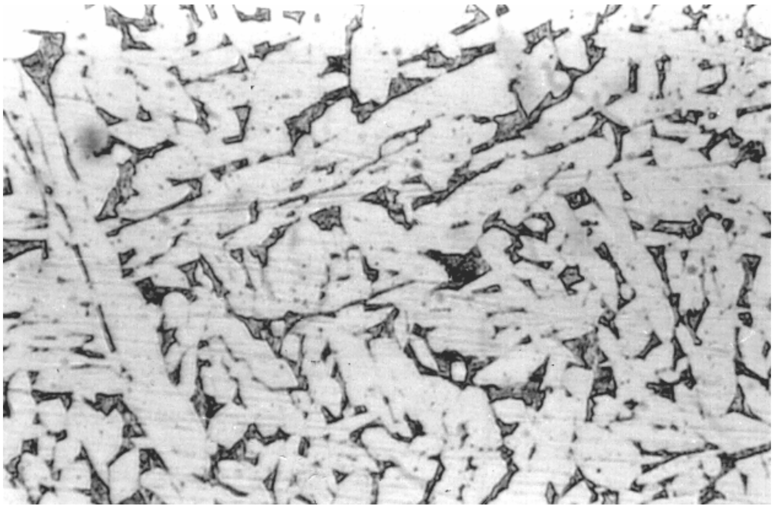
Typical composition: 7 % to 15 % Al or 4 % to 9 % Sn, up to 5 % Fe, may contain Mn and/or Ni, balance Cu
Microstructure: Cu-bearing intermetallic compounds in a copper alloy solid-solution matrix
Main characteristics: — Hardness: depends upon Al and Sn content; low alloy, about 140 Brinell; high alloy, about 300 Brinell — Seldom heat treated — Machineable — Low alloys have high impact resistance; high alloys have low impact resistance — Very good metal-to-metal wear resistance — Low Al alloys have good corrosion resistance in media such as seawater; high-Al alloys are not recommended for corrosion-resistant applications. — Service is generally limited to temperatures below about 200 °C
Applications: Bearing surfaces, gears, cams, corrosion-resistant overlays for some alloys
 Copper alloy solid solution plus copper alloy eutectic. Composition: 9,84 % Al, 0,92 % Fe, balance copper. Photomicrograph provided by Tokuden Co., Ltd., Japan. **Microstructure of Type Cu-BT, ×100** (*continued*)

Table 30 (*continued*)



×400

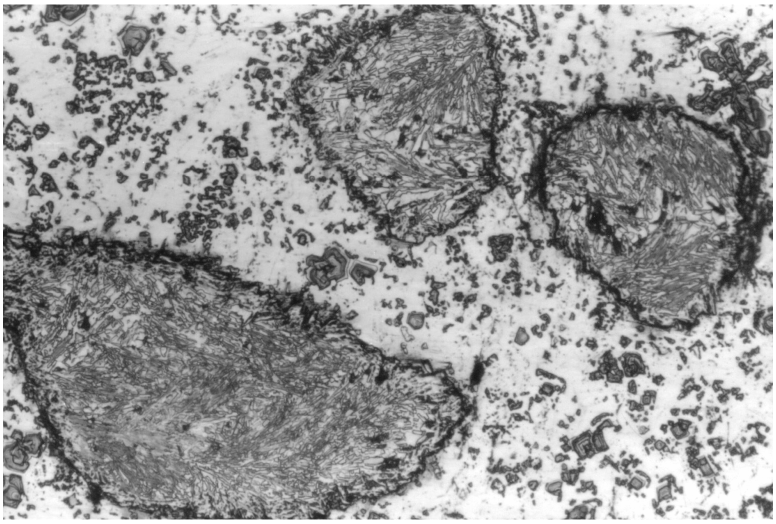
Photomicrograph provided by Tokuden Co., Ltd., Japan.

7.12 W-Fe Group (tungsten carbide in an iron matrix)

See Table 31.

Table 31 — W-Fe Group

Typical composition: 40 % to 60 % WC and/or W_2C, balance Fe
Microstructure: Chunks of unmelted tungsten carbide in a steel matrix
Main characteristics: — Hardness (as deposited): matrix – 30 R_C to 60 R_C — Particles: about 2 400 HV20 — Heat treatment serves no useful purpose — Not machineable, grinding only — Low impact resistance — Exceptional abrasion resistance where particles are concentrated. There is a tendency for the particles to sink to the bottom of a weld deposit, so that the top portion of the deposit will wear much more rapidly than the bottom. — Low corrosion resistance
Applications: Rock drill bits, tool joints, augers, excavator teeth, agricultural implements



Unfused chunks of tungsten carbide embedded in an iron-base matrix.

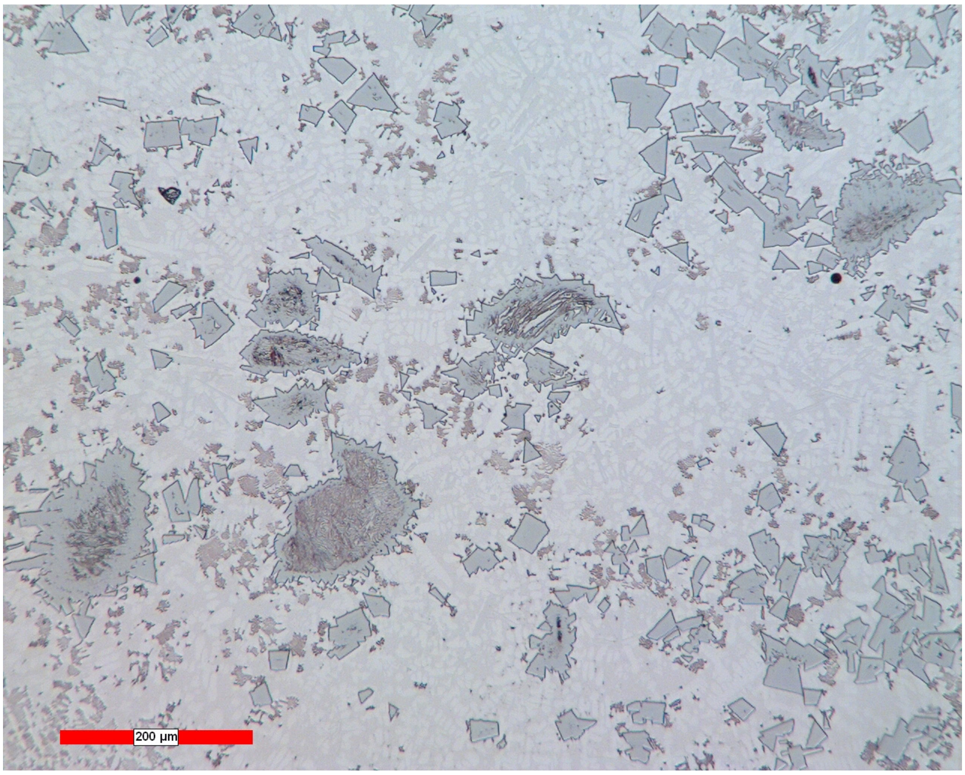
Photomicrograph provided by Nippon Engineering Industry Service, Japan.

Microstructure of Type W-Fe Deposit

7.13 W-Ni Group (tungsten carbide in a nickel-base alloy matrix)

See Table 32.

Table 32 — W-Ni Group

Typical composition: 40 % to 60 % WC and/or W_2C, balance nickel-base alloy
Microstructure: Chunks of unmelted tungsten carbide in a nickel-base alloy matrix
Main characteristics: — Hardness (as deposited): matrix – 30 R_C to 60 R_C — Particles: about 2 400 HV20 — Heat treatment serves no useful purpose — Not machineable, grinding only — Low impact resistance — Exceptional abrasion resistance where particles are concentrated. There is a tendency for the particles to sink to the bottom of a weld deposit, so that the top portion of the deposit will wear much more rapidly than the bottom. — Moderate corrosion resistance
Applications: Dredges, rock drill bits, tool joints, augers, excavator teeth, agricultural implements
 ×150 Microstructure of Ni-W group: approximate composition: 2,5 % C, 0,7 % Si, 45 % W, 1,0 % B, balance Ni. The small angular particles are WC and the larger particles are W_2C. The matrix is a Ni-Cr-B-Si eutectic. Photomicrograph provided by The Stoody Company (a division of Thermadyne Industries).

Annex A
(informative)

Types of wear and factors governing the severity of wear phenomena

Two cases can be distinguished: metal-to-metal wear, and wear of metals by minerals (abrasive wear). Table A.1 describes the main factors involved in metal-to-metal wear and the main factors involved in abrasive wear.

Table A.1 — Classification of wear processes

Metal-to-metal	Friction adhesion	Factors	Contact pressure Speed of translations – rotations Stationary and transitory temperature fields Lubrication
		Characteristics	Transfer of material from the softer to the harder material. Occurrence of superficial cracking perpendicular to the direction of displacement.
		Examples	Guides, sliding surfaces, journals, etc.
	Thermomechanical fatigue	Factors	Contact pressure Alternating mechanical stresses Temperature cycling Forced water cooling (corrosion) Presence of interposed oxides (abrasion)
		Characteristics	Network cracking, microspalling, fire cracking, oxidation, abrasion
		Examples	Forging tools, wire-drawing tools, hot extrusion tools, steel mill and continuous caster rolls
Metal-to-mineral abrasion	Sliding abrasion	Factors	Low pressure, low relative speeds (slow erosion)
		Examples	Chutes, gravity conveyors, P. Wurth blast-furnace charging channels
	Grinding abrasion	Factors	High pressure, low relative speeds
		Examples	Conveyor screws, extrusion equipment, dry or wet mixer blades
	Gouging abrasion	Factors	High pressures combined with high impacts
		Examples	Crusher jaws, cones, blades and hammers
	Erosion	Factors	Fine mineral particles in gas streams, high speeds, laminar or turbulent flows
		Examples	Valve seats, blast-furnace bell seats, ventilator blades
	Cavitation	Factors	Fine mineral particles in liquid streams, high speed, turbulent flows
		Examples	Ship propellers, hydroturbine injectors, and wheels
Additional factors:	Temperature:	plays an aggravating role if it exceeds ~ 700 °C, possibly induces an additional oxidation factor.	
	Corrosion:	plays an aggravating role in some of the above-mentioned situations.	

Annex B
(informative)

General considerations on basic factors governing wear resistance

B.1 Resistance to corrosion and oxidation

Resistance to corrosion and oxidation is generally obtained through the formation of a continuous and stable film of metallic oxides on the surfaces that are subjected to such types of wear or degradation. The chromium oxide films have proved to be among the most protective, and therefore corrosion- and oxidation-resistant alloys generally are of the family of the high-chromium alloy types. In practice, high-chromium austenitic alloys are used to fight corrosion and oxidation but, on certain occasions, high-chrome ferritic alloys may be used or even recommended.

B.2 Resistance to high temperatures

When high temperatures are involved, the wear resistance is mainly dependent on the metallurgical stability of the considered alloys (stability of the microstructure). The precipitation of secondary hardening particles, the isothermal transformation of a matrix, and the formation of intermetallic compounds at high service temperatures may affect the wear resistance. Hardness at temperature and creep resistance are two significant properties of the heat-resistant alloys, which, in most cases, are of the high-chromium, nickel, or cobalt-base alloy type.

B.3 Metal-to-metal wear resistance

When metal-to-metal wear is involved, it is important to look for alloys with a certain level of hardness, with low friction coefficients or, on some occasions, with “self-lubricating” properties. Grey or spheroidal graphite irons and chromium alloyed ferritic-bainitic or martensitic alloys give favourable results. Alloys that can be work hardened, such as austenitic alloys, are often used, namely when a certain degree of impact is present. Copper-base alloys, such as P-bronzes and Al-bronzes, also give favourable results for metal-to-metal wear, as do many of the cobalt-based alloys. Cu and Al alloys are candidates in the case of a lower range of temperatures, whereas Co alloys are designed more specifically for service in the higher range of temperatures.

B.4 Metal-to-mineral wear resistance

There are basically two criteria that are used in view of evaluating the abrasion resistance of alloys. The first criterion is the hardness. The second criterion is based on various abrasion tests, usually based upon mass loss or volume loss (see Annex C). As illustrated in Figure D.1, the hardness correlates to a limited extent with the abrasion resistance. However, for alloys containing carbides, the resistance against abrasive wear is much more significantly influenced by the nature, the amounts, and the types of carbide present than it is by the hardness. Thus, for alloys containing significant amounts of carbides, the standardized abrasion tests are much more meaningful than the hardness.

Annex C
(informative)

Abrasive-wear-resistance test methods

As can be seen from Table A.1, the types and relative severity of abrasive wear depend on a large number of factors. In most practical situations, these factors are difficult if not impossible to quantify and, when acting in combination, their relative importance is in most cases equally difficult to evaluate. Therefore, whether downscaled simulation test methods or conventional test methods are used to determine the merits of hardfacing alloys, the results obtained are, in the vast majority of instances, not directly in correlation with what is really occurring in practice. What is obtained, however, is a relative ranking of alloys, and this ranking, depending on the test parameters, may be different from test method to test method.

Various test methods have been developed to simulate a variety of conditions encountered in practice. Some of these methods are standardized by ASTM, as shown in Table C.1:

Table C.1 — ASTM abrasive-wear test methods

ASTM standard	Abrasive-wear test method
ASTM G65	Dry low-stress abrasion
ASTM G99	High-stress abrasion
ASTM G105	Wet low-stress abrasion
ASTM G75	Slurry abrasion
ASTM G76	Solid-particle impingement
ASTM G73	Liquid impingement

The low stress abrasion test (ASTM G65) is widely used in industry, along with the high stress abrasion test.

As an illustration of the ASTM G65 Test Method, Figure C.1 shows a general overview of the test apparatus.

Figure C.2 shows a close-up view of the test coupon pressed against the wheel and of the abrasive material flowing between the wheel and the coupon.

Figure C.3 shows two coupons after testing. This figure illustrates the difference in wear resistance between two different alloys having the same hardness but different microstructures. Both samples have about 55 Rockwell C hardness, but the uncracked sample deposit belongs to the M1 Group (low-alloy martensite), while the cracked sample deposit belongs to the NE Group (near eutectic austenite-carbide iron). It is easily seen that the wear scar in the cracked sample is much smaller than the wear scars in the uncracked sample. These differences can be quantified by measurement of the mass or volume loss resulting from the test (see Annex D).

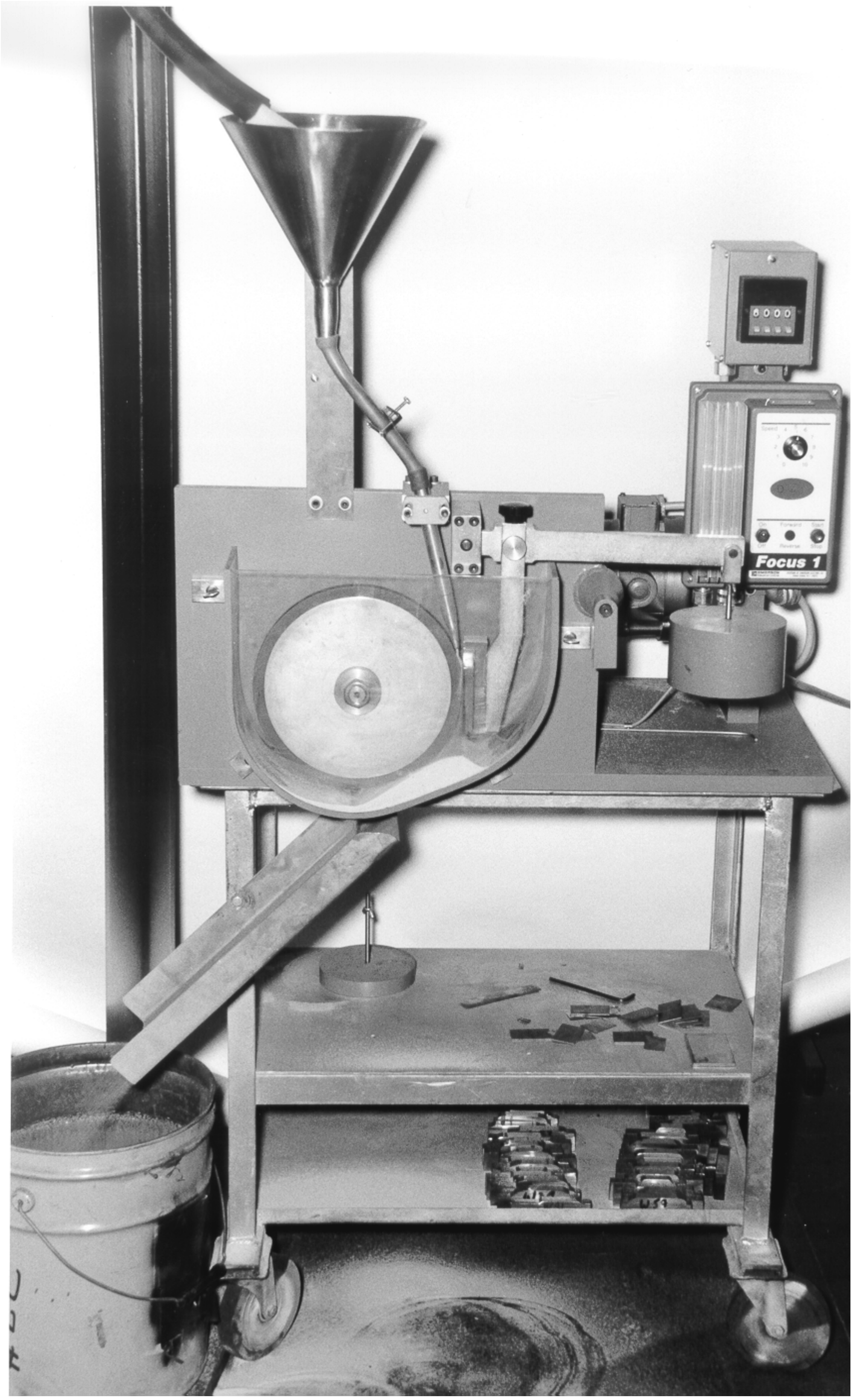


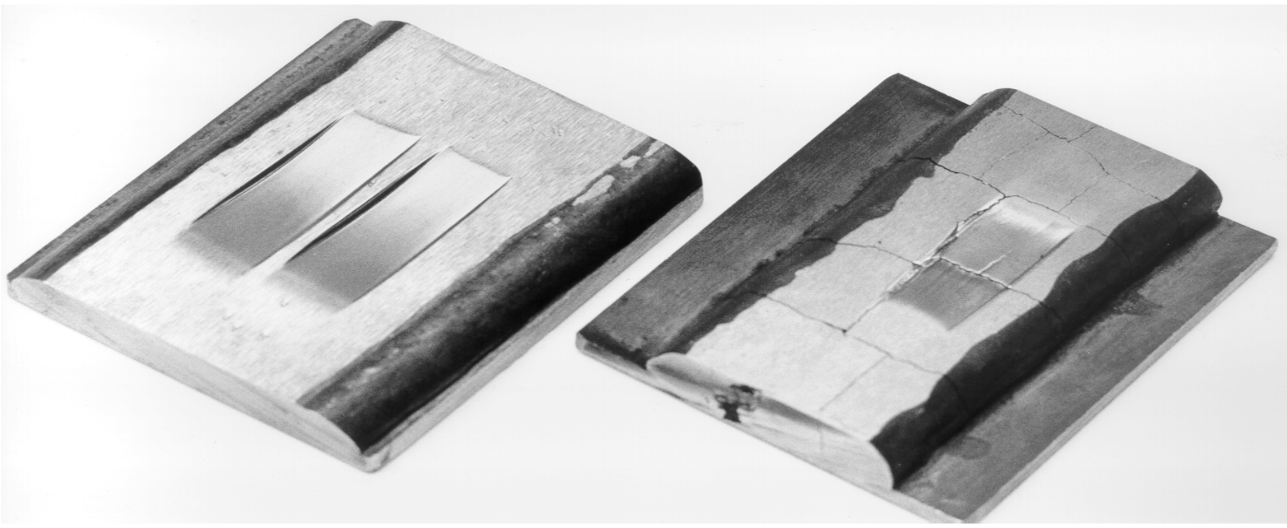
Photo provided by The Lincoln Electric Company, USA.

Figure C.1 — ASTM G65A low-stress abrasion test apparatus

Note the thin stream of quartz particles passing through the interface between the rubber wheel and the test specimen.

Photo provided by The Lincoln Electric Company, USA.

Figure C.2 — ASTM G65A abrasion test apparatus — Close-up view



Both deposits are of about 55 R_C hardness. The left specimen is from the M1 deposit group, while the right specimen is from the NE group. Note the larger wear scars on the M1 specimen.

Photo provided by The Lincoln Electric Company, USA.

Figure C.3 — ASTM G65A test specimens after testing

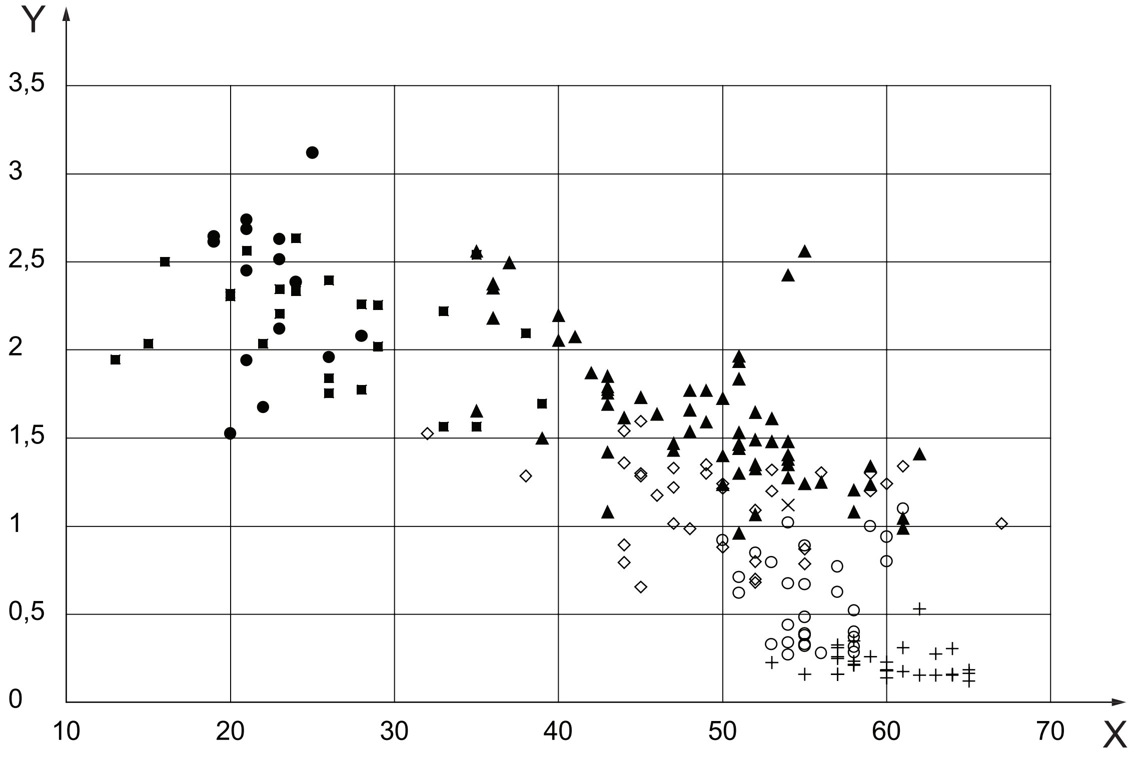
Annex D
(informative)

Practical guidance

D.1 Abrasion resistance versus hardness and microstructure

A common misconception is that hardness is a reliable indication of abrasion resistance. It is true that, for a given microstructure type, better abrasion resistance correlates with higher hardness. However, across the broad spectrum of iron-base hardfacing alloys indicated in Table 1 and Figure 1, the microstructural grouping is more important than the hardness in indicating abrasion resistance.

An extensive study of the abrasion resistance of iron-base hardfacing deposits has been done (Reference [14] in the Bibliography). Figure D.1, taken from this study, shows ASTM G65 mass loss versus hardness. While a general trend towards lower mass loss with greater hardness is detectable, the scatter is very large. However, when the same abrasion results are plotted against the mass fraction of carbon, as in Figure D.2, the scatter is greatly reduced, and a clear and strong trend of reduced mass loss (greater abrasion resistance) with increasing mass fraction of carbon is evident. The microstructure type is indicated by the symbol used for each data point. While the key is not quite the same as is given in Table 1 of Reference [14], it is clear that the microstructure types group with the mass fraction of carbon, as is also evident from Figure 1.

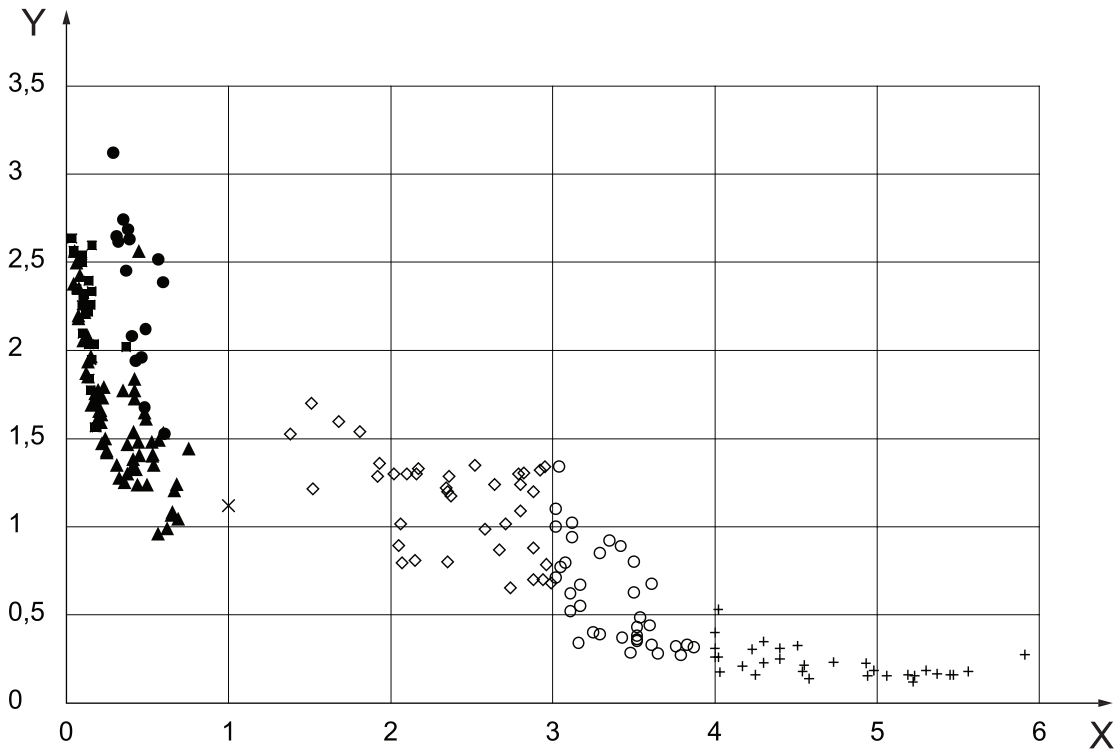


Key

X deposit hardness, Rockwell C

Y ASTM G65A mass loss, g

Figure D.1 — ASTM G65A abrasion test results versus deposit hardness



Key

X deposit, % C

Y ASTM G65A mass loss, g

Figure D.2 — ASTM G65A abrasion test results versus carbon content

Therefore, it can be concluded that the first criterion in selecting a hardfacing alloy should be microstructure. In particular, hardfacing deposits of the primary carbide with eutectic (PKE) group provide far better abrasion resistance than do the low-alloy martensite (M1) or tool-steel martensite (M2) groups, with similar hardness.

D.2 Effects of dilution

There are relatively few instances where the substrate being hardfaced has approximately the same composition as the hardfacing alloy. Examples where the compositions are similar include rebuilding of austenitic manganese rock crushers and hammer-mill hammers with austenitic manganese (AM Group); rebuilding low-alloy steel gears, sprockets, pulleys, and tractor undercarriage idlers with low-alloy steel build-up compositions (FS Group); rebuilding tool-steel dies with tool-steel martensite (M2 Group); and rebuilding high-chromium white cast-iron coal-crusher rolls with primary carbide compositions (PKE Group).

The vast majority of applications involve deposition of the hardfacing alloy on a substrate that is dissimilar in composition and microstructure. In such cases, the first layer of deposited hardfacing material, due to dilution with the substrate, can easily be quite different in composition and microstructure from subsequent layers.

Consider, for example, the deposition of austenitic manganese hardfacing on a high-carbon steel rail. A typical rail steel composition is 0,8 % C, 0,5 % Mn. A typical austenitic manganese hardfacing composition (AM Group) is 1 % C, 14 % Mn. With 40 % dilution, which is quite realistic in many welding processes, the first layer of hardfacing will then consist of about 0,9 % C, 8,6 % Mn. Examination of Figure 1 indicates that this composition will lie somewhere in the region of martensite and austenite (MA Group), which is prone to cracking. Then deposition of additional layers of austenitic manganese often results in cracking near the bond line with the entire deposit peeling out of the rail. Possible solutions to this problem include using a much richer alloy of austenitic manganese steel composition (20 % to 25 % Mn), or using a hardfacing composition from the austenitic chromium-manganese (AMC) group. Either composition, with 40 % dilution, will result in a stable austenite first layer, with much less likelihood of cracking.

Furthermore, consider the case of overlaying a carbon steel or low-alloy steel with a commercially common primary carbide with eutectic composition, such as 4,5 % C, 25 % Cr. With 40 % dilution, the first layer of hardfacing will have an approximate composition of 2,8 % C, 15 % Cr. Again referring to Figure 1, this first layer will have a microstructure of primary austenite with a eutectic. Reference to Figure D.2 indicates that, in low-stress abrasion, this first layer would wear at a rate three to five times as fast as the undiluted hardfacing deposit composition. Then, to get the full benefit of the hardfacing composition chosen, it would be necessary to deposit at least three layers of the 4,5 % C, 25 % Cr material, or to find a way to reduce dilution significantly.

Therefore, it can be concluded that Figure 1 can be very useful in anticipating dilution effects on hardfacing deposit microstructures.

Annex E
(informative)

Cross-references to national standards

Most standards classify hardfacing products based primarily upon the chemical composition of the deposit, rather than upon the microstructure of the deposit. This results, in many cases, in one chemical composition class including more than one microstructure type. Table E.1 provides cross-references to the more common national standards.

Table E.1 — Cross-references to national standards

Microstructure type	EN 14700 alloy symbol	DIN 8555 alloy group	AWS A5.13 and A5.21 alloy group	JIS Z 3251 and Z 3326 alloy group	AS/NZS 2576:2005 alloy group
Fe-FS	Fe1, Fe3	1	Fe1, Fe1A, Fe2	F2A	11
Fe-M1	Fe1, 2, 3, 4, 6, 7, 13	1, 2	Fe3, Fe5	F2B	14
Fe-M2	Fe2, 3, 4, 6	3, 4	Fe6, Fe8	F3B, F3C, F5A, F5B	15
Fe-M3	Fe7, Fe8	5, 6	—	F4A, F4B	16
Fe-M4	Fe5	—	—	—	—
Fe-MA	Fe6, Fe8	6	—	—	17a
Fe-MK	Fe4, 6, 8, 13	6	FeCr-A2, FeCr-E1	—	19
Fe-MEK	—	6	Fe4, Fe7	—	18
Fe-A	Fe10, 11, 12	9	—	—	13
Fe-AF	Fe10, 11, 12	9	—	—	13
Fe-AM	Fe9	7, 8	FeMn-A, FeMn-B, FeMn-C, FeMn-D, FeMn-E, FeMn-F, FeMn-G, FeMn-H	FMA, FMB	12
Fe-AMC	Fe9	8	FeMnCr	FME	17b
Fe-AK	Fe9	10	—	—	—
Fe-PAE	Fe14	10	Fe7, FeCr-A, FeCr-A3, FeCr-A3A, FeCr-A5, FeCr-A6, FeCr-A8	FCrA	21, 22, 23, 25, 26
Fe-NE	Fe14	10	FeCr-A, FeCr-A1A, FeCr-A3, FeCr-A3A, FeCr-A4, FeCr-A6, FeCr-A7, FeCr-A8, FeCr-A9	FCrA	21, 22, 23, 25, 26
Fe-PKE	Fe14, 15, 16	10	FeCr-A1A, FeCr-A3, FeCr-A4, FeCr-A7, FeCr-A8, FeCr-E2, FeCr-A9, FeCr-A10	FCrA	24, 25, 26
Fe-KKA	Fe16	10	FeCr-E3, FeCr-E4	FCrA	24
Co-CS	Co1	20	CoCr-E	CoCrD	41

Table E.1 (*continued*)

Microstructure type	EN 14700 alloy symbol	DIN 8555 alloy group	AWS A5.13 and A5.21 alloy group	JIS Z 3251 and Z 3326 alloy group	AS/NZS 2576:1996 alloy group
Co-PC	Co1, Co2	20	CoCr-A, CoCr-B	CoCrA, CoCrB	42, 44
Co-NE	Co2, Co3	20	CoCr-B, CoCr-C, CoCr-F	CoCrA, CoCrB, CoCrC	42, 44
Co-PKE	Co2, Co3	20	CoCr-C, CoCr-G	CoCrC	43
Co-LP	—	20	—	—	—
Ni-NS	Ni2, Ni4	23	NiCrMo-5A	—	51
Ni-B	Ni3	—	—	—	52
Ni-CB	Ni2	22	NiCr-A, NiCr-B, NiCr-C, NiCr-C, NiCr-E	—	52
Ni-LP	Ni2, Ni4	23	—	—	—
Cu-BS	Cu1	30, 32	CuSi, CuNi	—	61, 64
Cu-BT	Cu1	30, 31	CuAl-A2, CuAl-B, CuAl-C, CuAl-D, CuAl-E, CuSn-A, CuSn-C, CuSn-D, CuNiAl, CuMnNiAl	—	62, 63, 65, 66, 67
W-Fe	Fe20	21	WC	FWA	32, 33, 34, 35
W-Ni	Ni20	—	—	—	36, 53

Bibliography

[1] AS/NZS 2576:2005, *Welding consumables for build-up and wear resistance*

[2] ASTM G65, *Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus*

[3] ASTM G73, *Standard Practice for Liquid Impingement Erosion Testing*

[4] ASTM G75, *Standard Test Method for Determination of Slurry Abrasivity (Miller Number) and Slurry Abrasion Response of Materials (SAR Number)*

[5] ASTM G76, *Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets*

[6] ASTM G99, *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*

[7] ASTM G105, *Standard Test Method for Conducting Wet Sand/Rubber Wheel Abrasion Tests*

[8] AWS A5.13, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*

[9] AWS A5.21, *Composite Surfacing Welding Rods and Electrodes*

[10] DIN 8555, *Filler metals used for surfacing*

[11] EN 14700, *Welding consumables — Welding consumables for hard-facing*

[12] JIS Z 3251, *Covered electrodes for hardfacing*

[13] JIS Z 3326, *Arc welding flux cored wires for hardfacing*

[14] KOTECKI, D.J. and OGBORN, J.S. Abrasion resistance of iron-based hardfacing alloys. *Welding Journal* **74**(8), 1995, pp. 269-s to 278-s

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