Hard facing by welding in marine environment

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We think that welding is synonymous with joining. That is not always the case. Metal parts often fail their intended use not because they fracture, but because they wear down, which causes them to lose dimension and functionality. Hard facing by weld build up, also known as hard surfacing is the application of build-up or wear-resistant weld metals to a part's surface by means of welding.

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General information

Classification systems for welding consumables like electrodes are there in order to guide users towards the products chemistry, mechanical properties and application area.

Hard facing consumable manufacturers do have classification systems available. Despite this fact some manufacturers do not inform classification at all, or informs “similarly” to a specific classification.

Contrary to standard consumables for joining, hard facing consumables with few exceptions have no general approvals from the classification societies (DNV/GL, ABS, BV, LRS). Classification societies will however approve specific hard facing jobs from case to case.

The electrodes for hard facing are produced in two ways: 1) Like other standard electrodes, a metal rod coated with a mix of alloys and deoxidizers. 2) tubular rod filled with an alloy mix and then dipped in a coating or has a coating extruded over it.

Onboard a vessel there will with few exceptions be used MMAW (stick electrode welding) for hard facing. The consumable charts and comparison charts in this paper gives suggested stick electrodes for MMAW according to classification. There is also charts for Wire Welding processes using tubular Flux Cored Arc Welding wire (FCAW-S). This is referred to as Self-Shielded or as Open Arc wire.

The comparison charts are based on resemblance with regards to classification. Please note that the classifications alloy groups have lower and upper limit range on elements that can be quite considerable. This can also be the case for mechanical values (hardness). The comparison has not taken into account if the consumable is high or normal recovery type or if it can be used in different positions. The same applies if the consumable can be used for AC and/or DC current and polarity. It is therefore advisable to contact the manufacturer for finer details and for last updates.

In some cases, electrodes and wires is mentioned by their trade names based on their track records for a specific application. Other electrodes and wire brands with same classification is also mentioned but should be closely checked before use.

Benefits of hard facing:

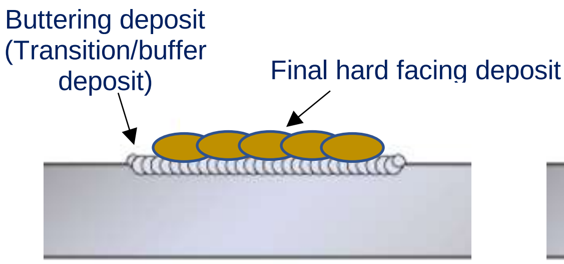
- Fewer replacement parts needed. There is no need to keep numerous spare parts when worn parts can be rebuilt.
- Prolong equipment life - Surfacing extends life 30 - 300 times, depending upon application, as compared to that of a non-surfaced part.
- Operating efficiency is increased by reducing downtime. Parts last longer, fewer shutdowns are required to replace them.
- Overall costs are reduced. Hard facing a worn metal part to like new condition is usually 25 - 75% of the cost of a replacement part.

Wear and tear on ships equipment makes maintenance in the form of Hard Facing Welding necessary. To keep operational cost down it is important to get it right first time using the right welding methods and consumables.

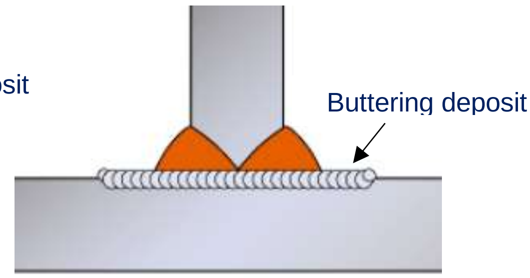
Terminology:

Hard facing and restoring worn parts frequently involves the following three steps:

1. Buttering, also referred to as buffer deposit or transition deposit is the addition of a weld deposit on the surface of a base material providing a suitable transition deposit, prior to the deposit of the final har facing deposit. Without the buttering deposit the final deposit would in some cases not metallurgically be compatible to the base material. Buttering can also be put to use in connection with joining of un-compatible base materials.



Buttering un-compatible
base material and hard facing



Buttering un-compatible
base materials

Buttering is also used in order to minimize dilution. Dilution will be explained later.

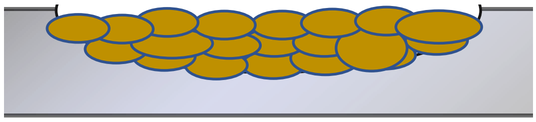
- Most hard facing alloys are limited to two or three layers, some only one. Therefore, some applications require that a buttering intermediate layer be used to build up the part close to finish dimensions prior to depositing a harder, more abrasion resistant alloy.
- When hard materials are used on soft base metals, such as mild steel, there is a tendency for the hard facing layer to “sink” into the soft base metal under high load conditions. This may result in spalling** of the hard-facing alloy. An intermediate buttering layer will help to prevent this from happening.
- Hard facing alloys sometimes check-crack* throughout the deposit. The buttering layer helps to prevent these cracks from propagating into the parent metal.
- If the surface conditions involve thermal cycling, large thermal property differences between the parent metal and the overlay can lead to fatigue problems and spalling. The deposition of a buffer layer provides a very effective transition between the weld and the overlay.
- Never us AWS E-7018*** electrode as buttering or build-up. It does not have the hardness and strength for hard facing applications.

* **Check-crack:** Some hard-facing weld deposits crack upon cooling, often referred to as "stress relief cracking" "check cracking" or "cross checking". Essentially all these terms refer to the same surface cracks observed on some hard-facing alloys. This is a normal phenomenon for very hard weld deposits. Many chromium carbides alloys check-crack when cooled to moderate temperatures. Others, such as the austenitic and martensitic families, don't crack when applied with proper welding procedures.

****Spalling** are flakes of a material that are broken off a larger solid body and can be produced by a variety of mechanisms, including as a result of impact or excessive rolling pressure.

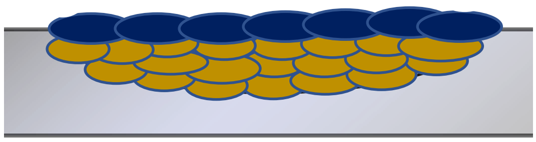
***AWS-E 7018: This is a common low hydrogen basic coated electrode for joining of mild and low alloyed steel.

2. Build-up layer — A build-up layer can consist of alloys that often resemble the parent metal alloy and are applied to severely worn parts to bring them back to dimension or act as a buffer for subsequent layers of a more wear-resistant hard facing deposit. Seriously worn areas should be rebuilt close to working size using tough, crack-resistant welding materials which can be deposited in an unlimited number of layers.



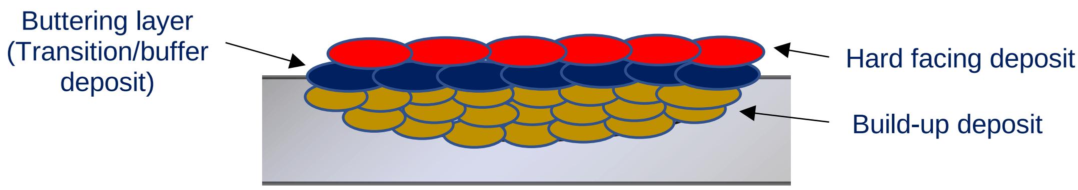
Build-up

As already explained the buttering layer, is used when necessary to overcome problems of incompatibility between base material and hard facing alloy. The use of a buttering layer is to provide a good base between the base metal and the hard facing. Great care must be taken when choosing the filler metal for the buttering layer. If differences in elasticity or thermal expansion between the base metal, buttering and hard facing deposit are too great, excessive stresses may be generated at the weld joints. This may cause it to fail prematurely.



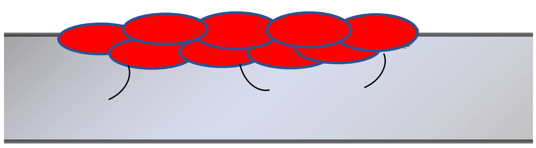
Buttering layer

3. Hard facing — Wear resistant surfaces deposited on the buttering or on build-up deposits extend service life. As mention previously hardfacing is usually limited to one, two, or three layers. The hard-facing layer must be an alloy that can take the type of wear that apply to the part.



Hard facing

Hard facing without a build-up and buttering deposit can lead to cracks developing into the base material.



Consumable Selection

The whole idea of consumable selection is to find a consumable and welding process that in combination is the most efficient for the application, suits the base material and to the extent posible withstand the type of wear that the part will encounter. Welding consumable selection for hard surfacing depends upon three major factors:

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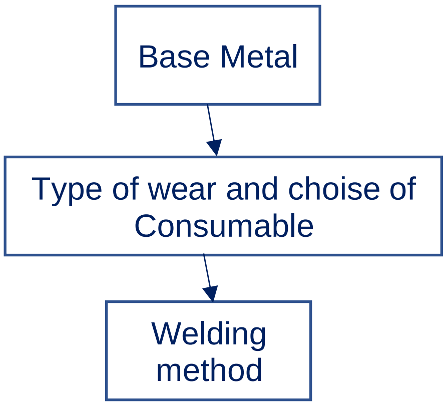


Base Metal

This primarily affects the choice of build-up and/or buttering materials. The following base metals can be hard-faced:

Stainless steels
Manganese steels
Cast irons and steels
Nickel-base alloys
Copper-base alloys

For exsample manganese steel is used for components subject to high impact loading. If so, one have to build up to size using a weld deposit suitable to manganese steel.

For base material identification please go to:

www.teandersen.com> Welding Library > Methods for identifying Metals & Recommendation for Welding.

Type of wear and choise of consumable

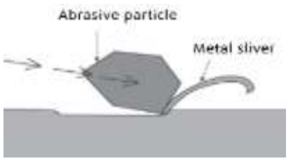
The primary consideration in selecting the final hard facing layers is the type of wear to be encountered in service. There are six major types of wear: Abrasive, Impact, Cavitation, Adhesive, High Temperature and Corrosive. Onboard a dredger abrasion can account for roughly 50 % of equipment wear, Impact 25 %, Adhesive (Metallic/metal to metal) 10 %, Heat 5%, Corrosion 5%, Other (like cavitation) 5 %.

Note that abrasive wear is really a group of wear problems. It can be broken down into three main categories that are “Low-stress scratching abrasion”, “High-stress grinding abrasion” and “Gouging abrasion”. Abrasion is also refered to as erosion.

Wear factors

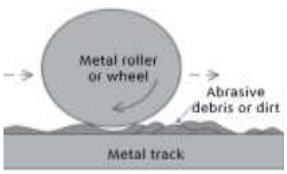
Abrasive → Abrasive wear is caused by foreign materials rubbing against a metal part. It can account for 50 - 60% of all wear onboard depending on type of vessel. Abrasive wear can be broken down into three main categories:

Low-stress scratching abrasion → Metal parts are worn away through the repeated scouring action of hard, sharp particles moving across a metal surface at varying velocities. The velocity, hardness, edge sharpness, angle of introduction and size of the abrasive particles all combine to affect the amount of abrasion.



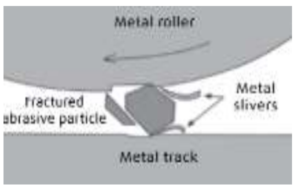
Carbide containing alloys (particularly chrome-carbide) are used successfully to resist low-stress abrasive wear. Due to the absence of impact, the relatively brittle high carbon chromium steel alloys are well suited for low-stress abrasive applications.

High-stress grinding abrasion → This results when small hard abrasive particles are forced against a metal surface with enough force that the particle is crushed, in a grinding mode. Most often the compressive force is supplied by two metal components with the abrasive sandwiched between the two. The surface becomes scored and surface cracking can occur.



There are examples of softer, tough alloys outperforming harder alloys in grinding abrasion applications. The range of alloys used successfully includes austenitic manganese, martensitic irons, and some carbide containing alloys (usually smaller carbides, like titanium carbide) in a tough matrix.

Gouging abrasion → When high-stress or low-stress abrasion is accompanied by some degree of impact and weight, the resulting wear can be extreme. The metal surface receives prominent gouges and grooves when massive objects (often rock) are forced with pressure against it.



Carbide containing alloys are used successfully when supported by a tough alloy - preferably austenitic manganese.

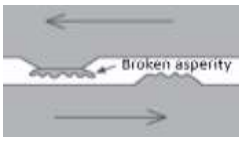
Impact

Impact is defined as the rapid application of a compressive load, produces momentary, extremely high mechanical stress on a metal component. When the stress exceeds the elastic limits of the metal, the metal deforms both beneath point and laterally across the surface away from the impact point.

Austenitic manganese steels (11 - 20% Mn) are the best choice for resisting heavy impact due to their work hardening characteristics. Although not as good as austenitic manganese, the martensitic alloys also offer moderate impact resistance.

Adhesive

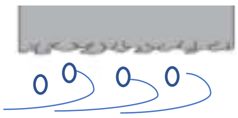
Adhesive (Metal-to-metal) wear, accounting for as much as 15% of all wear, results from non-lubricated friction of metal parts. Metal surfaces regardless of their finish, are composed of microscopic high and low areas. As metal surfaces slide against each other, the high areas are broken and tiny fragments of metal are torn away. The continual removal of metal roughens the working surface and contributes to even more rapid wear.



The martensitic hard surfacing alloys are a good choice for adhesive wear resistance. Other alloys, including austenitic manganese and cobalt based alloys, are also used successfully. Since softer alloys matched with a harder surface will wear rapidly, it is important not to overmatch a component when hard surfacing for adhesive wear resistance.

Cavitation

Cavitation is happening in fluid flow environment. The wear occurs from the collapse of cavitation bubbles. When a cavitation bubble collapses, the surrounding liquid rushes to refill the void and collides with the material surface. Transient pressures as high as 1.5 GPa* can form at the surface. Parts fallen victim to suction cavitation will have large chunks or very small bits of material missing, causing it to look like a sponge.



Cobalt-based alloys. Austenitic-type alloys containing controlled amounts of chromium, cobalt, silicon and manganese. Also, to be considered is ceramic polymers.

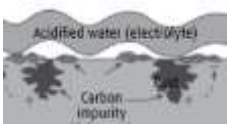
High temperature

Steel surfaces exposed to high temperatures for long periods of time can steadily deteriorate. Heat affects the metal's microstructure and generally reduces its durability. The wear resistance of most alloys is diminished when exposed to high heat in service due to softening through inadvertent tempering.

Martensitic steels containing 5 - 12% chromium are used extensively to combat thermal fatigue. Many chromium-carbide alloys retain their wear resistance up to temperatures of 650°C (1200°F) - service conditions over that temperature generally require a non-ferrous alloy. Cobalt based alloys belong to the group of deposits that can resist temperatures up to 900°C (1650°F).

Corrosive

Ferrous metals are subjected to many forms of corrosion, each of which can cause wear damage. The most common type of corrosion is rust. Rust transforms the surface of the metal into oxide which eventually flakes off, thus reducing the original thickness of the metal.



Corrosion as related to surfacing is usually a secondary wear factor. To meet this challenge, austenitic stainless steels (300 series) and nickel base alloys are preferred.

In most cases, the wear found will be a combination of two or more of the mentioned wear factors described.

* **GPa**: gigapascal. 1,5 GPa= 1500000000 Pa. A pascal (Pa) is the SI derived unit of pressure, stress, Young's modulus and ultimate tensile strength. It is a measure of force per unit area, defined as one newton per square meter.

Identifying the type of wear involved.

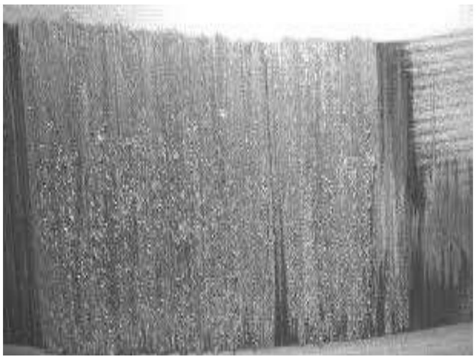
What is the part used for? What is the working environment? By simply asking these questions it will be possible to identify the type of wear involved. If abrasive wear check out the following: Type of product causing the wear. The hardness of the particles in the product. The size of the particles, edge sharpness, velocity and the angle of introduction towards the substrat.

Abrasive wear.
How to recognise: The surface will be ploughed and depending on product sometime have deep grooves.

Cavitation wear.
How to recognise: Pitting corrosion sometime over large surface areas. Will only take place in fluid flow environment.

Impact wear.
How to recognise: Collisions between solid bodies making dents in substate and in some cases cracks and chipping/ breaking off parts.

High Temperature wear
How to recognise: Pitting's and craters. Will only take place in hot environment.



Adhesive wear
How to recognise: Scratched surface. Tiny metal fragments to be found.

Corrosive wear
How to recognise: Oxidised surface. Sometime oxide flakes.

Classification of electrodes for hard facing

After establishing type of wear, the next step is to decide on consumable to match the type of wear.
This can also involve type of butter/ build up consumable to use.
The classifications most referred to are DIN 8555, AWS A5.13 and DIN EN 14700.

Filler Materials for Surfacing According to DIN 8555

Exsample:
EutecTrode 6450
DIN 8555: E 7-UM-250 KPR

E 7-UM-250 KPR

E	Short symbol for Manual Metal Arc Welding
MSG	Short symbol for Solid wire Gas shielded arc welding
MF	Short symbol for tubular wire (metal or flux cored)

Short symbol	Alloy group and application
1	Unalloyed up to 0.4% C or low-alloyed up to 0.4% C and up to max. 5 % alloy constituents Cr, Mn, Mo, Ni in total; soft surfacing, e. g. build-up welding, buffering layers.
2	Unalloyed with more than 0.4% C or low-alloyed with more than 0.4%C and up to max. 5% alloy constituents Cr, Mn, Mo, Ni in total; Running wheels.
3	Alloyed, with the properties of hot working steel. Hot working tools
4	Alloyed, with the properties of high-speed steel. Cutting tools, mandrels, shear blades, cutters, drill bits.
5	Alloyed with more than 5% Cr and low C-content (up to approx. 0.2%C) for scale-resistant (also against sulphurous gases) and from 12% Cr-content corrosion-resistant surfacing, e. g. valve parts, plungers, furnace parts
6	Alloyed with more than 5% Cr and higher C-content (approx. 0.2 - 2.0% C) cutting tools, shear blades, rollers for cold rolling mills
7	Mn austenite with 11 to 18% Mn and more than 0.5% C and up to 3% Ni. Surfacing large surfaces, e. g. wear plates, jaw plates, digging teeth, bolts
8	Cr-Ni-Mn-austenite crusher parts for medium stress, switch tongue, rails, water turbine parts
9	Cr-Ni-steel (corrosion and heat resistant) corrosion and heat resistant surfacing
10	High C-content and high Cr-alloyed with and without additional carbide former, repairs on mining and steel plant equipment, surfacing on machine parts in the construction industry and agriculture, overburden excavators, sinter crushers
20	Co-based, Cr-W-alloyed, with or without Ni and Mo fittings of all types, valve seats of exhaust valves in combustion engines, valve seats of steam engines, pump shafts and similar parts which are exposed to heavy corrosion and erosion
21	Carbide-based (sintered, cast or filled) tools and machine parts for working in stony earth, drills and similar tools, press screws in the ceramic industry
22	Ni-based, Cr-alloyed, Cr-B-alloyed valves, screws, shafts, e.g. for concrete pumps
23	Ni-based, Mo-alloyed with or without Cr hot working tools, contact surfaces of valves in chemical apparatuses, claddings at working edges of cuttings from Ni-Cr-Mo-alloys which are used for work at high temperatures
30	Cu-based, Sn-alloyed bearing shell, slides, shafts, valves, housings, snail and helical gear wheels, guide and running wheels, fittings
31	Cu-based, Al-alloyed machine parts and fittings in the chemical industry, food, paper and electrical industry
32	Cu-based, Ni-alloyed. Distillatory, sea water pipes, condensers, coolers, chemical apparatuses, heat exchangers

E 7-UM-250 KPR

Symbol	Type
GW	rolled
GO	cast
GZ	drawn
GS	sintered
GF	filled
UM	coated

E 7-UM-250 KPR

Classification of hardness	
Hardness class	**Hardness degree**
40	37-42 HRC
45	>42-47 HRC
50	>47-52 HRC
55	>52-57 HRC
60	>57-62 HRC
65	>62-67 HRC
70	>67 HRC
150	125-175 HB
200	>175-225 HB
250	>225-275 HB
300	>275-325 HB
350	>325-375 HB
400	>375-450 HB

E 7-UM-250 KPR

Symbol	Properties of weld metal
C	
G	Abrasion resistant
K	Work-hardenabel*
N	Non- magnetizable
P	Impact resistant
R	Stainless
S	Edge-holding (high speed steel)
T	Creep-resistant (high speed steel)
Z	Heat-resistant temp> 600°C (1112°F)
The wear properties of the weld metal depend on a work-hardening after-treatment. It can be achieved by subsequent hammering or pressing, but also without such after treatment if the weld metal is exposed to compressive stress, rolling or impact stress during operation.	

AWS A5.13/A5.13M:2010
Specification for surfacing electrodes for shielded metal arc welding (MMAW)

Example:
EutecTrode 6450
AWS A5.13: E Fe Mn Cr

E Fe Mn Cr

Table 1
Iron Base Surfacing Electrodes—Chemical Composition Requirements[a]

AWS Classification	Annex A Reference	UNS Number[e]	Deposit Composition, weight percent[b,c,d]											
			C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb(Cb)	Fe	Other Elements, Total
EFe1	A7.1.1	W74001	0.04–0.20	0.5–2.0	1.0	0.5–3.5	—	1.5	—	—	—	—	Rem	1.0
EFe2	A7.1.1	W74002	0.10–0.30	0.5–2.0	1.0	1.8–3.8	1.0	1.0	0.35	—	—	—	Rem	1.0
EFe3	A7.1.2	W74003	0.50–0.80	0.5–1.5	1.0	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFe4	A7.1.3	W74004	1.0–2.0	0.5–2.0	1.0	3.0–5.0	—	—	—	—	—	—	Rem	1.0
EFe5	A7.1.4	W75110	0.30–0.80	1.5–2.5	0.90	1.5–3.0	—	—	—	—	—	—	Rem	1.0
EFe6	A7.1.5	W77510	0.6–1.0	0.4–1.0	1.0	3.0–5.0	—	7.0–9.5	0.5–1.5	0.5–1.5	—	—	Rem	1.0
EFe7	A7.1.6	W77610	1.5–3.0	0.5–2.0	1.5	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFeMn-A	A7.1.7	W79110	0.5–1.0	12–16	1.3	—	2.5–5.0	—	—	—	—	—	Rem	1.0
EFeMn-B	A7.1.7	W79310	0.5–1.0	12–16	1.3	—	—	0.5–1.5	—	—	—	—	Rem	1.0
EFeMn-C	A7.1.7	W79210	0.5–1.0	12–16	1.3	2.5–5.0	2.5–5.0	—	—	—	—	—	Rem	1.0
EFeMn-D	A7.1.7	W79410	0.5–1.0	15–20	1.3	4.5–7.5	—	—	0.4–1.2	—	—	—	Rem	1.0
EFeMn-E	A7.1.7	W79510	0.5–1.0	15–20	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFeMn-F	A7.1.7	W79610	0.8–1.2	17–21	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFeMnCr	A7.1.8	W79710	0.25–0.75	12–18	1.3	13–17	0.5–2.0	2.0	1.0	—	—	—	Rem	1.0
EFeCr-A1A	A7.1.9	W74011	3.5–4.5	4.0–6.0	0.5–2.0	20–25	—	0.5	—	—	—	—	Rem	1.0
EFeCr-A2	A7.1.10	W74012	2.5–3.5	0.5–1.5	0.5–1.5	7.5–9.0	—	—	—	—	1.2–1.8	—	Rem	1.0
EFeCr-A3	A7.1.11	W74013	2.5–4.5	0.5–2.0	1.0–2.5	14–20	—	1.5	—	—	—	—	Rem	1.0
EFeCr-A4	A7.1.9	W74014	3.5–4.5	1.5–3.5	1.5	23–29	—	1.0–3.0	—	—	—	—	Rem	1.0
EFeCr-A5	A7.1.12	W74015	1.5–2.5	0.5–1.5	2.0	24–32	4.0	4.0	—	—	—	—	Rem	1.0
EFeCr-A6	A7.1.13	W74016	2.5–3.5	0.5–1.5	1.0–2.5	24–30	—	0.5–2.0	—	—	—	—	Rem	1.0
EFeCr-A7	A7.1.13	W74017	3.5–5.0	0.5–1.5	0.5–2.5	23–30	—	2.0–4.5	—	—	—	—	Rem	1.0
EFeCr-A8	A7.1.14	W74018	2.5–4.5	0.5–1.5	1.5	30–40	—	2.0	—	—	—	—	Rem	1.0
EFeCr-E1	A7.1.15	W74211	5.0–6.5	2.0–3.0	0.8–1.5	12–16	—	—	—	—	4.0–7.0	—	Rem	1.0
EFeCr-E2	A7.1.15	W74212	4.0–6.0	0.5–1.5	1.5	14–20	—	5.0–7.0	1.5	—	—	—	Rem	1.0
EFeCr-E3	A7.1.15	W74213	5.0–7.0	0.5–2.0	0.5–2.0	18–28	—	5.0–7.0	—	3.0–5.0	—	—	Rem	1.0
EFeCr-E4	A7.1.15	W74214	4.0–6.0	0.5–1.5	1.0	20–30	—	5.0–7.0	0.5–1.5	2.0	—	4.0–7.0	Rem	1.0

[a] Single values shown are maximum percentages. Rem = Remainder.
[b] The weld metal shall be analyzed for the specific elements for which values, or a "g," are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.
[c] SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System.*
[d] Includes cobalt.
[e] Sulfur is restricted to 0.015% maximum.
[f] This AWS classification is intended to correspond to the same classification that appears in AWS A5.6, *Specification for Copper and Copper-Alloy Covered Electrodes.* Because of revision dates the composition ranges may not be identical.
[g] These elements must be included in "Other Elements, Total."

Table 2
Nickel and Cobalt Base Surfacing Electrodes—Chemical Composition Requirements

AWS Classification	Annex A Reference	UNS Number[d]	Deposit Composition, weight percent[a, b, c] C	Mn	Si	Cr	Ni	Mo	Fe	W	Co	B	V	Other Elements, Total
ECoCr-A	A7.2.1	W73006	0.7–1.4	2.0	2.0	25–32	3.0	1.0	5.0	3.0–6.0	Rem	—	—	1.0
ECoCr-B	A7.2.2	W73012	1.0–1.7	2.0	2.0	25–32	3.0	1.0	5.0	7.0–9.5	Rem	—	—	1.0
ECoCr-C	A7.2.3	W73001	1.7–3.0	2.0	2.0	25–33	3.0	1.0	5.0	11–14	Rem	—	—	1.0
ECoCr-E	A7.2.4	W73021	0.15–0.40	1.5	2.0	24–29	2.0–4.0	4.5–6.5	5.0	0.50	Rem	—	—	1.0
ENiCr-C	A7.3.1	W89606	0.5–1.0	—	3.5–5.5	12–18	Rem	—	3.5–5.5	—	1.0	2.5–4.5	—	1.0
ENiCrMo-5A	A7.3.2	W80002	0.12	1.0	1.0	14–18	Rem[e]	14–18	4.0–7.0	3.0–5.0	—	—	0.40	1.0
ENiCrFeCo	A7.3.3	W83002	2.2–3.0	1.0	0.6–1.5	25–30	10–33	7.0–10.0	20–25	2.0–4.0	10–15	—	—	1.0

[a] Single values are maximum percentages. Rem = Remainder.
[b] The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.
[c] Sulfur and phosphorus contents each shall not exceed 0.03%.
[d] SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System.*
[e] Includes incidental cobalt.

Table 4
Mesh Size and Quantity of Tungsten Carbide (WC) Granules in the Core of Tungsten Carbide Electrodes

AWS Classification[a, b]	U.S. Standard Mesh Size of Tungsten Carbide Granules[c]	SI Mesh Size mm	Quantity of Tungsten Carbide (WC1 + WC2) Granules, weight percent
EWCX-12/30	thru 12–on 30	thru 1.70–on 0.60	60
EWCX-20/30	thru 20–on 30	thru 0.85–on 0.60	60
EWCX-30/40	thru 30–on 40	thru 0.60–on 0.43	60
EWCX-40	thru 40	thru 0.43	60
EWCX-40/120	thru 40–on 120	thru 0.43–on 0.13	60

[a] "X" designates the type of tungsten carbide granules; X = 1 for WC1 granules, X = 2 for WC2 granules, X = 3 for a blend of WC1 and WC2 granules.
[b] These AWS classifications have been transferred to AWS A5.21:2001 without a change in classification for solid bare electrodes and rods and with the prefix "ERC" for electrode/rod made from metal or flux cored stock.
[c] The mesh size of the tungsten carbide granules may vary from that specified above, provided that no more than 5% of the granules are retained on the "thru" sieve, and that no more than 20% passes the "on" sieve.

AWS A5.13/A5.13M:2010 covers hard facing electrodes:
Iron Base Surfacing Electrodes Table 1.
Nickel and Cobalt Base Surfacing Electrodes Table 2.
Copper Base Surfacing Electrodes Table 3 (page 65).
Tungsten Carbide Surfacing Electrodes Table 4 (partly covered).

Filler Materials for Hard-facing According to DIN EN 14700

Example:
UTP electrode BMC
DIN EN 14700: EFe9

EFe9

Symbols for range of product form

Symbol	Product form (consumable)
E	Covered electrode
S	Solid wire and solid rod
T	Cored wire and cored rod
R	Cast rod
B	Solid strip
C	Sintered rod, cored strip and sintered strip
P	Metal powder

Symbols for range of chemical composition

Alloy abbreviation *a	**Suitability**	**Chemical composition in % (by mass)**									
		C	Cr	Ni	Mn	Mo	W	V	Nb	Others	Remainder
Fe1	p	< 0.4	<3.5	–	0.5–3	<1	<1	<1	–	–	Fe
Fe2	p	0.4–1.2	<7	<1	0.5–3	<1	<1	<1	–	–	Fe
Fe3	s t	0.2–0.5	1–8	<5	<3	<4.5	<10	<1.5	–	Co, Si	Fe
Fe4	s t (p)	0.2–1.5	2–6	<4	<3	<10	<19	<4	–	Co, Ti	Fe
Fe5	c p s t w	<0.5	<0.1	17–22	<1	3–5	–	–	–	Co, Al	Fe
Fe6	g p s	<2.5	<10	–	<3	<3	–	–	<10	Ti	Fe
Fe7	c p t	<0.2	4–30	<6	<3	<2	–	<1	<1	Si	Fe
Fe8	g p t	0.2–2	5–18	–	0.3–3	<4.5	<2	<2	<10	Si, Ti	Fe
Fe9	k (n) p	0.3–1.2	<19	<3	11–18	<2	–	<1	–	Ti	Fe
Fe10	c k (n) p z	<0.25	17–22	7–11	3–8	<1.5	–	–	<1.5	Si	Fe
Fe11	c n z	<0.3	18–31	8–20	<3	<4	–	–	<1.5	Cu	Fe
Fe12	c (n) z	<0.08	17–26	9–26	0.5–3	<4	–	–	<1.5	–	Fe

Symbols for range of chemical composition (Continue)

Alloy abbreviation *a	Suitability	Chemical composition in % (by mass)									
		C	Cr	Ni	Mn	Mo	W	V	Nb	Others	Reminder
Fe13	g	<1.5	<6.5	<4	0.5–3	<4	–	–	–	B, Ti	Fe
Fe14	g	1.5–4.5	25–40	<4	0.5–3	<4	–	–	–	–	Fe
Fe15	g	4.5–5.5	20–40	<4	0.5–3	<2	–	–	<10	B	Fe
Fe16	g z	4.5–7.5	10–40	–	<3	<9	<8	<10	<10	B, Co	Fe
Fe20	c g t z	Hard materials*b	–	–	–	–	–	–	–	–	Fe
Ni1	c p t	<1	15–30	Rest	0,3–1	<6	<2	<1	–	Si, Fe, B	Ni
Ni2	c k p t z	<0,1	15–30	Rest	<1,5	<28	<8	<1	<4	Co, Si, Ti	Ni
Ni3	c p t	<1	1–15	Rest	0,3–1	<6	<2	<1	–	Si, Fe, B	Ni
Ni4	c k p t z	<0,1	1–15	Rest	<1,5	<28	<8	<1	<4	Co, Si, Ti	Ni
Ni20	c g t z	Hard materials*b	–	–	–	–	–	–	–	–	Ni
Co1	c k t z	<0.6	20–35	<10	0.1–2	<10	<15	–	<1	Fe	Co
Co2	t z (c s)	0.6–3	20–35	<4	0.1–2	–	4–10	–	–	Fe	Co
Co3	t z (c s)	1–3	20–35	<4	<2	<1	6–14	–	–	Fe	Co
Cu1	c (n)	–	–	<6	<15	–	–	–	–	Al, Fe, Sn	Cu
Al1	c n	–	–	10–35	<0.5	–	–	–	–	Cu,Si	Al
Cr	g n	1–5	Rest	–	<1	–	–	15–30	–	Fe, B, Si, Zr	Cr

c: corrosion-resistant
g: abrasion-resistant
k: work-hard enable
n: non-magnetizable
p: impact-resistant
s: cutting power-resistant
t: heat resistant
z: scale-resistant
w: age-artificially
() perhaps not suitable for all alloys in this list

*a Alloys not listed in this table should be marked "similar" with the prefix "Z".

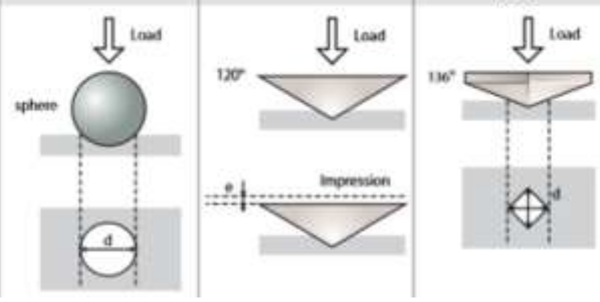
*b Tungsten carbide or cemented tungsten carbide broken or spherical.

The DIN EN 14700 classification is divided in two compulsory parts and 3 optional parts. The two compulsory parts have been explained above (product form, chemical composition range and suitability). The 3 optional parts give information towards percentage of the most important alloying elements, hardness of the weld metal and auxiliary materials like shielding gas and fluxes. Most manufacturers only inform the consumables two compulsory parts.
The symbol for the hardness is informed in this table in case it is informed by manufacturer.

Symbols for range of hardness

Symbol	Range of hardness
150	125 HB and ≤ 175 HB
200	> 175 HB and ≤ 225 HB
250	> 225 HB and ≤ 275 HB
300	> 275 HB and ≤ 325 HB
350	> 325 HB and ≤ 375 HB
400	> 375 HB and ≤ 450 HB
40	37 HRC and ≤ 42 HRC
45	> 42 HRC and ≤ 47 HRC
50	> 47 HRC and ≤ 52 HRC
55	> 52 HRC and ≤ 57 HRC
60	> 57 HRC and ≤ 62 HRC
65	> 62 HRC and ≤ 67 HRC
70	> 67 HRC

Explenation to Hardness Test

Penetrator	Brinell	Rockwell	Vickers
Type	Hardened steel / Tungsten carbide	Diamond	Diamond
Shape	Sphere	Cone	Pyramid with square base
Principle			

"Penetration hardness tests" are widely used in hard facing operations to characterise the materials involved (base metal, external element or deposited metal).
The Vickers, Brinell and Rockwell hardnesses scales are frequently used in hardfacing applications. The choice depends on the material and the test conditions.

The Brinell test (HB) uses a spherical indenter made of hardened steel or a tungsten carbide alloy. As the resulting impression is quite large, it is easy to interpret the measurement. In addition, the surface of the zone to be measured does not require much preparation, light grinding is sufficient.

The Rockwell test (HRC) is used for materials with a higher hardness (greater than 450HB). A conical diamond indenter is used, and the depth of penetration is converted directly to a hardness reading. Careful positioning of the tester and the part are necessary for accurate measurements.

The Vickers test (HV) covers all materials (soft and hard). The surface to be tested must be polished which takes time, so this test is usually confined to the laboratory. The material is penetrated with a pyramid-shaped diamond. In addition to its wide applicability, the Vickers test can also provide macro and micro-hardness readings.

It is important not to confuse "hardness" with “toughness” and “resistance to abrasion”.

Hardness conversion table

HB	HV	HRC	Tensile Strength N/mm2	HB	HV	HRC	Tensile Strength N/mm2
80	80	36,4*	275	300	300	30,3	1010
85	85	42,2*	295	310	310	31,5	1040
90	90	474*	315	320	320	32,7	1070
95	95	52,0*	325	330	330	33,8	1100
100	100	56,4*	345	340	340	34,9	1140
105	105	60,0*	365	350	350	36,0	1170
110	110	63,4*	380	359	360	37,0	1205
115	115	66,4*	390	368	370	38,0	1235
120	120	69,4*	410	376	380	38,9	1265
125	125	72,0*	420	385	390	39,8	1295
130	130	74,4*	440	392	400	40,2	1325
135	135	76,4*	460	400	410	41,5	1355
140	140	78,4*	470	408	420	42,4	1385
145	145	80,4*	490	415	430	43,2	1400
150	150	82,2*	500	423	440	44,0	1430
155	155	83,8*	520	430	450	44,8	1460
160	160	85,4*	540	436	460	45,5	1490
165	165	86,8*	550	443	470	46,3	1520
170	170	88,2*	570	451	480	47,0	1540
175	175	89,6*	590	459	490	47,7	1570
180	180	90,8*	610	467	500	48,3	1600
185	185	91,8*	620	481	520	49,6	1660
190	190	93,0*	640	495	540	50,9	1765
195	195	94,0*	660	508	560	52,1	1825
200	200	95,0*	670	521	580	53,3	1715
205	205	95,8*	685	535	600	54,4	1875
210	210	96,6*	715	548	620	55,4	1930
215	215	97,6*	705	561	640	56,4	1980
220	220	98,2*	735	574	660	57,4	2030
225	225	99,0*	755	588	680	58,4	2080
230	230	19,2	765	602	700	59,3	2130
235	235	20,2	785	615	720	60,2	2170
240	240	21,2	805	627	740	61,1	2215
245	245	22,1	825	639	760	61,9	2255
250	250	23,0	835	650	780	62,7	
255	255	23,8	855	661	800	63,5	
260	260	24,6	875	672	820	64,3	
265	265	25,4	885	682	840	65,0	
270	270	26,2	900	692	860	65,7	
275	275	26,9	920	701	880	66,3	
280	280	27,6	940	711	900	66,9	
285	285	28,3	950		920	67,5	
290	290	29,0	970		940	68,0	
295	295	29,6	990				

Examples of Vickers hardness values for common materials involved in wear:

Material	Hardness (HV)	Material	Hardness (HV)
Coal	32	Iron ore	470
Gypsum	36	Glass	500
Lime	110	Feldspar	600/750
Calcite	140	Agglomerate	770
Fluorspar	140	Quartz	900/1280
Coke	200	Corundum	1800

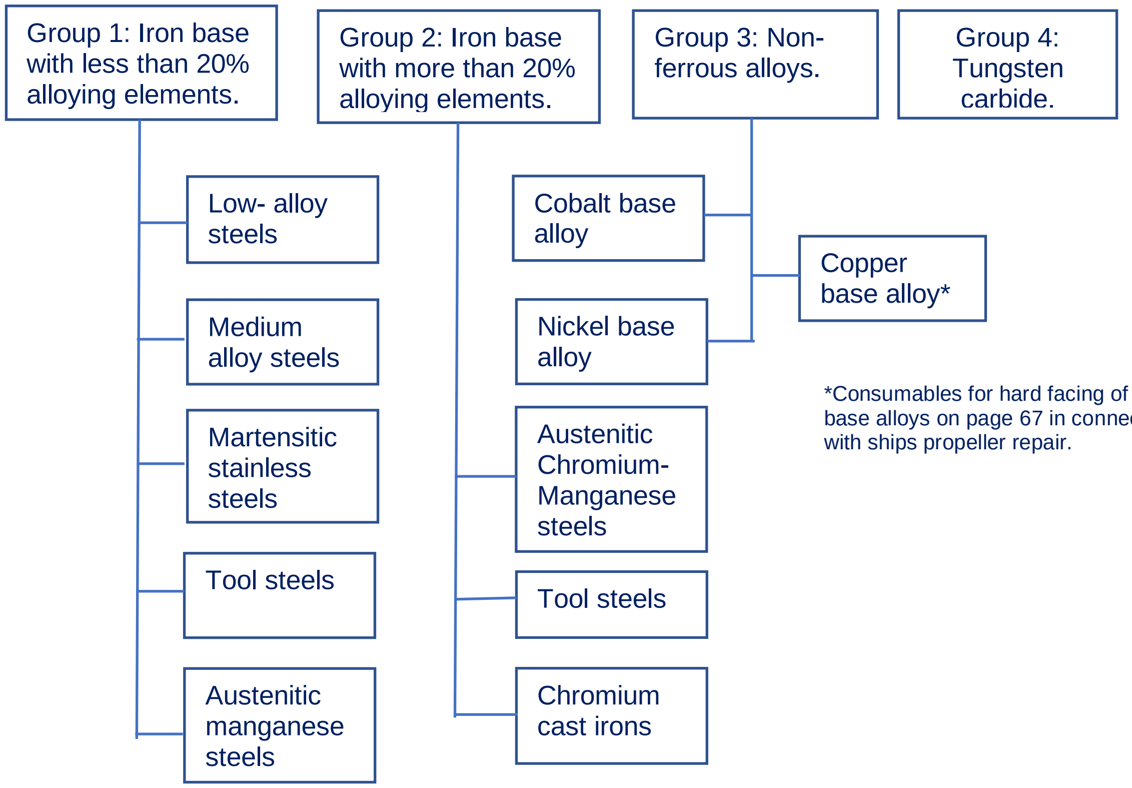
The chemical composition given in DIN EN 14700 for the filler metal informs the product's functionality. Each element or combination of elements in an alloy has a particular function; it can be related to weldability, or especially to the deposit's physical or mechanical characteristics. In practice, when choosing a filler metal, it is advisable to decide why an element is added. This step is necessary for making the most appropriate choice. The below table describes the main influence of alloy elements in the deposit.

Main influence of alloy elements in the weld deposit.

	Description	**Hardness & Carbides**	**Performance at temperature**	**Resistance to shock**	**Ductility**	**Corrosion**
C	**Carbon** is the principal hardening and strengthening element in iron-based alloys. It can combine with other elements to form carbides (hard phases). The alloys' strength and hardening capability improves as the carbon content increases, whilst elongation and weldability and machinability decrease.	▲▲▲▲	▲▲	▼▼▼▼	▼▼▼▼	▼▼
Cr	**Chromium** improves heat resistance. Steels require a minimum chromium content of around 13% to render them corrosion resistant. Higher Cr contents improve corrosion and heat resistance. Chromium tends to reduce thermal conductivity. Chromium is a generator of carbides which has the effect of improving resistance to wear.	▲▲▲▲	▲▲	▼▼▼▼	▼▼▼	▲▲▲▲
Mo	**Molybdenum** belongs to the category of elements that increase strength and resistance to corrosion and is therefore often used in Cr-Ni austenitic steels.	▲▲	▲▲▲	▲▲	▼	▲▲
Nb	**Niobium** is a powerful generator of hard carbides. This element can also be used as a stabiliser in refractory austenitic steels.	▲▲▲▲	▲▲▲	▲	▼▼▼	▲
V	**Vanadium** is a generator of carbides and is used to reduce sensitivity to overheating. Therefore, this element is often found in high speed hot working steels.	▲▲▲	▲▲	▼	▼▼▼	---------
W	**Tungsten** is a powerful generator of very hard carbides. This element increases the resistance to high temperatures and is therefore used for tool steel applications.	▲▲▲▲	▲▲▲▲	▼▼	▼▼▼▼	----------
Ti	**Titanium** combines easily with other elements such as oxygen (deoxidising effect) and carbon. Titanium carbide forms fine particles, providing good resistance to external shocks.	▲▲▲	-----------	▲▲▲	▼	▲
Mn	**Manganese** plays an important role by deoxidizing and desulphurising weld metal. Where there is over 12% manganese with a high carbon content, the deposit is austenitic, thus providing excellent resistance to shock and wear due to work hardening. Over 18% Manganese, the deposit becomes non-magnetic.	------------	------------	▲▲▲	▲▲▲	-----------
Ni	**Nickel** is not a carbide former. It substantially improves impact strength in construction steels. Where its content exceeds 7% and there is a high chromium content, the structure becomes austenitic.	------------	▲▲	▲▲	▲▲	▲
Co	**Cobalt** promotes heat resistance by slowing grain growth. In addition, it provides excellent resistance to corrosion and erosion.	▲▲	▲▲▲▲	▲▲	▲▲	▲▲▲▲

Hard facing family group.

Filler metals for hard facing can be divided into four groups.



*Consumables for hard facing of copper base alloys on page 67 in connection with ships propeller repair.

Regarding Iron-base alloys:

Martensitic. This includes all hardenable steels with Rockwell hardness from 20 to 65. This group, similar to tool steel, hardens upon cooling. They are good for metal-to-metal and abrasive wear. They also can withstand a great deal of impact.

Austenitic. Austenitic alloys include work-hardening steels, such as manganese and stainless. This group generally is soft when it's welded and hardens only after the weld metal is worked. They have good impact properties and moderate abrasion resistance. The stainless-steel family is good for corrosion resistance.

Metal carbide. These alloys contain large amounts of metal carbides in a soft, tough matrix and are good for severe-abrasion applications. The alloys that contain large amounts of chromium* and carbon are known as the chromium carbide family and are closer to a cast iron or white iron. Their hardness's are from 40 HRC to 65 HRC. Alloys that contain large amounts of tungsten and carbon belong to the tungsten carbide family. Some contain small amounts of chromium and boron that form borides and are good for severe-abrasion applications.

*Chromium carbide
Generally, these are iron-base alloys that contain high amounts of chromium (greater than 18 percent) and carbon (greater than 3 percent). These elements form hard carbides (chromium carbides) that resist abrasion. The deposits frequently check-crack about every 12mm (1/2"), which helps relieve stress from welding. Their low friction coefficient also makes them desirable in applications that require material with good slip. Generally speaking, the abrasion resistance increases as the amount of carbon and chromium increases, although carbon has the most influence. Hardness values range from 40 HRC to 65 HRC. They also can contain other elements that can form other carbides or borides that help increase wear resistance in high-temperature applications. These alloys are limited to two or three layers.

Group1: Iron base with less than 20 % alloying elements

Low-alloy steels

These filler metals contain a maximum 0.2% C and hardness after welding does not exceed 250HV. They are produced for use in the rebuilding of parts prior to hardfacing. They provide a metallurgical transition between the soft base metal and the hardfacing. The deposited metal has good mechanical properties and resists compression well. Their composition however, means that these filler metals respond poorly to wear.

Low-alloy steel electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EFe1
Typical chemical composition: C 0.15%, Mn 1.50%, Si 0.80%, Cr 1.00%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 260 HB.
Crack-resistant deposit. Repair, rebuilding and buttering of castings Applications: shafts, rollers, wheels.

Medium alloy steels

The most commonly used filler metals are those that deposit a martensitic - bainitic structure. These are low - cost filler metals with alloying additions to give wear resistance. As well as carbon, they may contain: Carburigenic elements, such as chromium and molybdenum. They also have elements that refine the structure, such as manganese. Weld deposit hardness may vary from 250 to 700HV. It is useful to note that deposits with hardness less than 300HV are easy to machine, whilst surfacing exceeding 50HRC is usually impossible to machine. The harder the deposit, the greater its resistance to abrasion under low or moderate stresses. Such materials are frequently found in earthmoving activities.

Medium alloy steel electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EFe1 As under Low-alloy steel.
DIN EN 14700: EFe8
Typical chemical composition: C 0.50%, Mn 1.50%, Si 2.50%, Cr 8.50%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 650 HB.
Self-tempering deposit for hard facing. Applications: bucket teeth and blades, slides, conveyor screws, etc.

Martensitic stainless steels

Martensitic stainless steels, with over 12 % Cr, offer good resistance to wear from thermal fatigue and to corrosion. These grades are ideal for applications where there is hot metal-to-metal wear. The addition of elements such as nitrogen and cobalt increases the resistance of these alloys to high temperatures and corrosion. Nitrogen reduces segregation of chromium carbides at the grain boundaries and provides improved resistance to pitting corrosion (PREN=Cr+3.3Mo+16N). Cobalt gives the deposit improved resistance to high temperatures and, therefore, to both thermal fatigue and high temperature corrosion. When surfacing a low or medium alloy base metal with martensitic stainless steels, it is advantageous to apply a special butter layer over-alloyed in chromium (~ 17%) to guarantee metallurgical soundness and to avoid cracking in service.

Martensitic electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EFe7
Typical chemical composition: C 0.05%, Mn 1.00%, Si 0.80%, Cr 17.50%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 220 HB.

Combination of corrosion, frictional wear and temperature resistance. Resists sea water and dilute organic acids. Can be polished. Applications: anti-corrosion coatings or buttering layer before martensitic stainless steel coatings - e.g. valve seats, shafts, pump bodies and rotors. The EFe7 group can also contain electrodes that provide high-carbon ferritic-martensitic stainless steel deposit alloyed with nickel, molybdenum and tungsten that provide resists thermal fatigue and gallin.

Tool steels (in group 1)

Electrodes for repair of tool steel have imited interest for use onboard. There are not many aplications, but they have been included in order to give a full picture of electrodes for hard facing. Tool steels are used for high temperature forming in repeated cycles. They must be able to withstand a temperature range of 500-600°C (932-1112°F) without softening. Elements such as molybdenum, vanadium, titanium, and tungsten are added to ensure this. Forging tools - knives, closed dies, hammers and mandrels - are made from these steels, or surfaced with them. They exhibit resistance to the combined effects of thermal fatigue, plastic deformation and fretting. Later, we shall see that other, more highly alloyed solutions are available, based on cobalt (Stelite) and nickel alloys.

Tool steel electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EFe3
Typical chemical composition: C 0.25%, Mn 2.00%, Si 0.80%, Cr 6.50, Mo 1.50, W 1.50, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 44 HRC
Application: For the construction and repair of hot working tooling: forging, stamping and deburring dies. Tooling for hot shearing, punches, inserts.
Low cracking sensitivity.

Austenitic manganese steels

Steels with 12 to 14% Mn have a soft austenitic structure (hardness ~ 200HV), with the capacity for surface workhardening when the part is subjected to high impacts. Hardnesses of around 500HV can be achieved. When cracks form in service, the lifetime of the surfacing is not necessarily compromised. In fact, this type of deposit shows high resistance to crack propagation. The 14% Mn grades contain about 1% carbon. This results in embrittlement if the cooling rate is too slow, due to precipitation of carbides at the grain boundaries. Welded components are often solution treated at 1000°C (1830°F) to give a purely austenitic structure. Unfortunately, solution annealing is not always possible. Excessive interpass temperatures and overly slow cooling must be avoided. When surfacing with 14 % Mn steel on a non or low alloy substrate, the use of an austenitic stainless buttering layer (AISI307 or AISI312) is highly advisable. This avoids any risk of creating a martensitic heat-affected zone. Without this intermediate layer, a brittle zone would form leading, under high impact, to spalling of the surfacing.

Austenitic manganese steel electrodes for hard facing can in DIN EN 14700 have grading :

DIN EN 14700: EFe9
Typical chemical composition: C 1.00%, Mn 14.00%, Si 0.50%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 200 HB, Work Hardened 46 HRC.
Applications: Must be used in combination with butter layer if application is hard facing of a non or low alloyd steel.

Group 2: Iron base with over 20 % alloying elements

Austenitic Chromium-Manganese steels

As with 14% Mn steels, austenitic chromium-manganese deposits are workhardening. However, because of their high alloy content, these products can be applied directly to non or low alloy substrates; with no risk of forming a martensitic structure at the interface. It should also be noted that the presence of chromium means flame-cutting cannot be used on this alloy.

Austenitic Chromium-Manganese steels electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EFe9
Typical chemical composition: C 0.40%, Mn 16.00%, Si 0.50%, Cr 14.00%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 240 HB, Work Hardened 48 HRC.
High rate of work-hardening. Non-magnetic deposit strongly resistant to impact and high pressure. Rebuilding, buffer layers and assembly of manganese steels. Applications: repair work on rail frogs and crossings, hammers, bars, cones and jaws for crushers.
DIN EN 14700: EFe10
Typical chemical composition: C 0.10%, Mn 6.00%, Si 0.50%, Cr 19.00%, Ni 9.00%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 180 HB, Work Hardened 47 HRC.
Highly resistant to cracking - austenitic structure that work-hardens strongly. Wide field of application: buffer layer before hardfacing, assembly of wear plates and armouring, and of manganese steels and dissimilar joints.

Tool steels (in group 2)

Alloying with cobalt, chromium and molybdenum is delivering a deposit performance very similar to cobalt base alloys. Withstand high temperature stresses up to 500-600°C (932- 1112°F).

Tool steels electrodes in group 2 for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: EZFe3
Typical chemical composition: C 0.15%, Mn 0.40%, Si 0.70%, Cr 14.00%, Ni 0.50%, Mo 2.50%, Co 12.50%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 47 HRC.
Gives similar performance to cobalt based alloys. High cracking resistance little affected by dilution, highly resistant to thermal shock, may be polished and keeps its properties to 550°C. Applications: traction rollers, valves for diesel engines, steam valves.

Chromium cast irons

These deposits are composed of hard phases in a matrix whose structure depends on the composition of the filler metal: martensitic, bainitic or austenitic. They are mainly used to resist wear by abrasion. In the case of low or moderate abrasion, deposits with an austenitic matrix are normally used. However a martensitic matrix is a better solution for high abrasion under pressure. The size of the hard phases (carbides, borides) and their distribution in the matrix have a direct influence on the deposit's resistance to abrasion. For example, for the same hardness, a surfacing with bigger and closely spaced carbides will tend to give better results than one with smaller particles. For applications involving severe abrasion under impact, a deposit containing titanium carbides provides good results. The fine regular distribution of hard phases provides excellent resistance to combined stresses.

Chromium cast irons electrodes for hard facing can in DIN EN 14700 have grading :

DIN EN 14700: EFe15
Typical chemical composition: C 5.00%, Mn 1.50%, Si 1.50%, Cr 27.00%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 61 HRC.
Highly abrasion resistant chromium carbide deposit. Combination of primary and eutectic chromium carbides in a tough matrix. Applications: design of high performance composite parts such as wear plates, mineral conveying equipment, dredger pumps, mixers and riddle plates.

DIN EN 14700: EFe16
Typical chemical composition: C 5.50%, Mn 0.50%, Si 1.50%, Cr 22.00%, Nb 6.00%, Mo 5.50%, W 2.00%, V 1.00%, Fe Rest.
Mechanical values: Hardness 3 layers: As welded 65 HRC.
Highly-alloyed chromium cast iron with a high concentration of complex carbides. Resists combined abrasion and impact at high temperatures. The properties are reached in only three layers. Applications: riddling, extractor fans.

Group 3: Non-ferrous alloy cobalt or nickel base

Cobalt base alloy

Cobalt alloys are often refered to as Stellite. This is however a trade name of Kennametal Inc. Proper name of the alloy group is Cobalt (Co). Cobalt alloys can be deposited using Manual Metal Arc Welding (strick electrode welding), Wire Welding (Flux Cored Arc Welding -Gas-shielded) or Tungsten Inert Gas welding (TIG). TIG welding will have less dilution with the base material and will normaly be the prefered welding process. On a industrial scale Plasma Transferred Arc Welding (PTA) and Laser processes are in use.

Cobalt based filler metals are mainly alloyed with carbon, chromium and tungsten, also sometimes with nickel and molybdenum. These alloys are especially suited to applications involving high temperatures up to 800°C (1475°F), retaining high hardnesses over time. Chromium provides a protective layer and thus plays an anti-oxidation role. As in iron-based alloy, chromium, tungsten and molybdenum combine with carbon to create hard carbides. The lower the carbon content, the better the resistance to cracking. The grade 21 cobalt alloy is largely insensitive to cracking and offers good impact characteristics. Cobalt alloy 6, being harder, offers improved resistance to abrasion at both high and low temperatures, but is less crack-resistant. These alloys are ideal for wear caused by metal-to-metal friction at high temperatures and in the presence of abrasives. Their low coefficient of friction, and their selfpolishing tendency, makes them highly scratch-resistant and helps maintain an excellent surface quality. To avoid cracking, any welding operation with this type of filler metal requires preheating. In most cases, grade 6 cobalt filler metals are welded using a preheating temperature of around 350°C (662°F), followed by slow cooling under thermal insulation.

Cobalt base alloy electrodes for hard facing can in DIN EN 14700 have grading:

DIN EN 14700: ECo3 (Stellite 1)
AWS A5.13: ECoCr-C
Typical chemical composition: C 2.30%, Mn 1.00%, Si 1.00%, Cr 28.50%, W 12.00%, Fe 4.00%, Co Rest.
Mechanical values: Hardness 3 layers: As welded 53 HRC.
Highest hardness of the cobalt base alloy range, offering excellent resistance to abrasion and corrosion. Self polishing, promotes scratch free sliding of abrasive materials.

DIN EN 14700: ECo2 (Stellite 6)
AWS A5.13: ECoCr-A
Typical chemical composition: C 1.05%, Mn 1.00%, Si 1.00%, Cr 28.50%, W 4.50%, Fe 4.00%, Co Rest.
Mechanical values: Hardness 3 layers: As welded 42 HRC.
Combines all the outstanding properties of the cobalt base alloys, including abrasion and erosion resistance. Deposit of intermediate hardness with good machinability. Wide field of applications: Valves and valve seats of marine engines, pump sleeves and shafts.

DIN EN 14700: ECo2 (Stellite 12)
AWS A5.13: ECoCr-B
Typical chemical composition: C 1.50%, Mn 1.00%, Si 1.00%, Cr 30.00%, Fe 4.00%, W 7.50%,Co Rest.
Mechanical values: Hardness 3 layers: As welded 45 HRC.
Moderate impact resistance combined with very good metal to metal wear properties. Very good for hot and cold abrasion. Retains hardness to high temperatures and less likely to crack than cobalt 1 alloys. Used on cams, shafts, tappets and push rods for engines, screw conveyors and seats and valves for oil and gas.

DIN EN 14700: ECo1 (Stellite 21)
AWS A5.13: ECoCr-E
Typical chemical composition: C 0.25%, Mn 1.00%, Si 1.00%, Cr 28.00%, Mo 5.50%, Ni 3.00%, Co Rest.
Mechanical values: Hardness 3 layers: Work Hardened 45 HRC.
Soft as welded but with work hardening hardness increases to above 45 HRC. Less crack sensitive than other alloys, it is used for build up and on large sections. Moderate cold abrasion but excellent metal to metal wear combined with good corrosion resistance. Used for integral seats and guides of large water and high pressure valve bodies, drop forging dies, pump shafts and sleeves, hot punches etc.

Note:
As ambient temperature goes up the cobalt deposits will gradualy come down in hardness. As an exsample cobalt alloy number 6:
Hardness as welded 20°C (68°F) 42HRC
Work Hardened up to 55 HRC
Elevated Temperatures:
At 400°C (750°F): down to 32HRC
At 600°C (1110°F): down to 28HRC
At 800°C (1475°F): down to 22HRC
At 900°C (1620°F): down to 20HRC

Comparison chart MMAW cobalt electrodes

Classification	KENNAMETAL	POLYMET	ESAB	UTP	LINCOLN	METRODE	CASTOLIN
DIN EN 14700: ECo3 AWS A5.13: ECoCr-C DIN8555: E20-UM-55-CSTZ	Stellite alloy 1	Cobalt alloy 1	OK 93.01	Celcit 701	Weartech WT1	-	EutecDur 9010 N
DIN EN 14700: ECo2 AWS A5.13: ECoCr-A DIN8555: E20-UM-40-CSTZ	Stellite alloy 6	Cobalt alloy 6	OK 93.06	Celcit 706	Weartech WT6	Cobstel 6	EutecDur 9060 N
DIN EN 14700: ECo2 AWS A5.13: ECoCr-B DIN8555: E20-UM-50-CSTZ	Stellite alloy 12	Cobalt alloy 12	-	Celcit 712	Weartech WT12	-	EutecDur 9120 N
DIN EN 14700: ECo1 AWS A5.13: ECoCr-E DIN8555: E20-UM-300-CKTZ	Stellite alloy 21	Cobalt alloy 21	-	Celcit 721	Weartech WT21	Cobstel 8	EutecDur 9080 N

Nickel base alloy

The nickel base alloys most commonly used for hard facing contain chromium, boron and carbon. They contain multiple hard phases (chromium carbides and borides) in a nickel-chromium matrix. This structure provides them with good resistance to oxidation up to ~ 950°C (1742°F) and enables them to maintain their hardness up to 500°C (932°F). Resistance to low or moderate abrasion is good irrespective of the process temperature and improves in proportion to carbon content. However, this type of alloy offers poor resistance to heavy abrasion under pressure. In addition, severe abrasion combined with heavy impacts will degrade the surfacing. These alloys are mainly used for applications involving abrasion and corrosion at high temperatures: valves, valve seats or spiral conveyor screws. Nickel base alloys should be deposited using Wire Welding (Flux Cored Arc Welding -Gas-shielded) or Tungsten Inert Gas welding (TIG). There are limited number for hardsurfacing nickel based consumables using Manual Metal Arc Welding (strick electrode welding).

Nickel base alloy electrodes for hard facing can in AWS A5.21 have grading :

AWS A5.21: ERCNiCr-A
Typical chemical composition: C 0.40%, Cr 11%, Si 2.20%, B 2.00%, Fe 2.50% Ni Rest.
Mechanical values: Hardness 1 layer: As welded 42 HRC.

AWS A5.21: ERCNiCr-B
Typical chemical composition: C 0.60%, Cr 13%, Si 3.70%, B 2,5%, Ni Rest.
Mechanical values: Hardness 1 layer: As welded 45-56 HRC.

AWS A5.21: ERCNiCr-C
Typical chemical composition: C 0.70%, Cr 14%, Si 4.00%, B 3.00%, Ni Rest.
Mechanical values: Hardness 1 layer: As welded 54-62 HRC.

This are nickel chrome silicon boron rods that form complex borides and carbides in a nickel matrix. Wide range of applications, such as metal to metal sliding, and a combination of wear, corrosion, oxidation or galling. Deposits maintain a high level of hardness up to 650°C (1200°F). Can be applied to low and medium carbon steels, cast iron and stainless steels.
Application area: Shaft sleeves, Bushings, Valves, Pump parts, Centrifuges.

Comparison list TIG Nickel based rods/wires

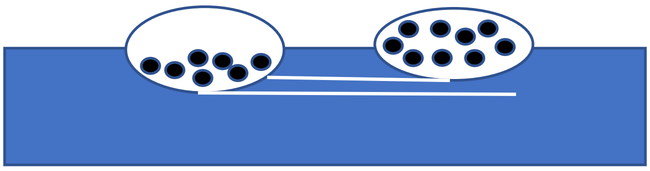
Classification	KENNAMETAL	POLYMET	COR-MET	LINCOLN
AWS A5.21: ERCNiCr-A	Deloro alloy 40	-	Coreface 84MC	WT-40 TIG
AWS A5.21: ERCNiCr-B	Deloro alloy 50	Polywear 50	Coreface 85MC	WT-50 TIG
AWS A5.21: ERCNiCr-C	Deloro alloy 60	Polywear 60	Coreface 86MC	WT-60 TIG

Group 4: Tungsten carbides

Tungsten carbides has the highest level of abrasion resistance available. The carbides can be deposited by:

- MMA (stick electrode) welding using tubular electrodes with steel matrix with a high percentage of tungsten carbides.
- Oxy- Acetylene/ TIG brazing using composite rods made up of tungsten-carbide particles retained in a bronze-nickel matrix.
- Wire welding using tubular wire that enables a high volume of tungsten carbide particles to be deposited.
- Laser and PTAW (plasma Transferred Arc welding) methods where tungsten powders are deposited.

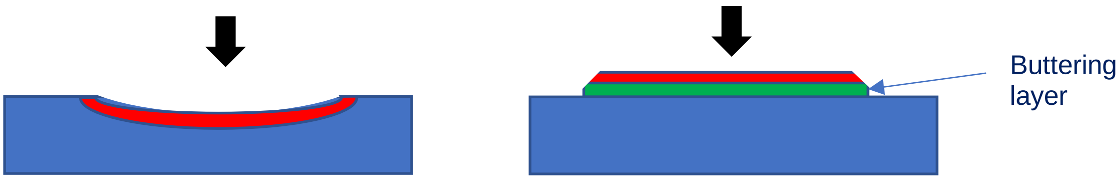
Application include: Hard facing oilfields and mining tools. Hard banding tool joints and drill collars. Of limited interest for applications onboard vessels except vessels and platforms involved in drilling operations.
Surfaced layers containing a dispersion of tungsten carbide can be produced with a filling of up to 60% of tungsten carbide grains, 100 – 250 microns in size. To ensure a good distribution of grains and good abrasion resistance, it is essential to use a low heat input. Welding parameters that are too high would result in the carbides dropping to the bottom of the weld pool.



Distribution of carbides in weld deposit depending on high energy (left) and low energy welding (right).

Choosing a buttering consumable

Buttering layers are recommended before hard facing. Using a low or medium alloy electrode for a buttering layer provides an intermediate hardness between the base metal and the hard facing. This solution should be used to avoid the hard facing being crushed into the "soft" base metal by an external load.



Preheating is often required during hardfacing to overcome cracking caused by contraction stresses, and to give a heat-affected zone that is more ductile and resistant to external stresses. Unfortunately, in many cases, it is difficult to apply homogeneous preheating. Therefore austenitic stainless steel buttering layers are often used. These can absorb the contraction stresses without cracking, largely removing the need for preheat.

One of the following consumables is usually selected:

- Austenitic stainless type AISI 309
- Austenitic stainless type AISI 312
- Austenitic stainless type AISI 307
- Austenitic stainless 14Cr-16Mn

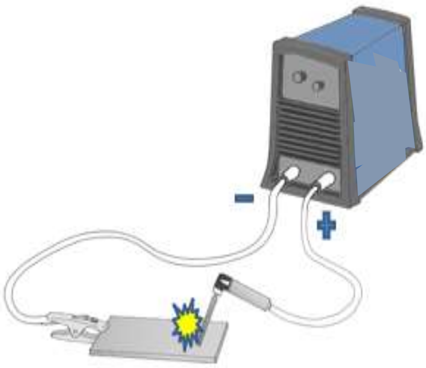
Two alloys are particularly recommended for creating a buttering buffer layer:
1 - The "austenitic stainless 312" alloy is recommended for its high tolerance to dilution, its noticeably higher hardnesses. It is therefore less subject to crushing under external constraints. For these reasons it is often used with austenitic hard facing alloys.
2 - The DIN EN 14700: EFe9 is recommended with martensitic hardfacing alloys. As it contains no nickel, there is no risk of softening the hard deposit.
Both of these consumables offer the advantage of a structure that is not susceptible to cold cracking and guarantee a stronger bond with the final hardfacing.

Welding Method

The choice of arc welding method depends primarily upon the size and number of components, available positioning equipment and frequency of hard facing. Realistic available methods are as follows onboard ships:

EN ISO 4063: 111 Manual Metal Arc Welding (MMAW)

Advantages:
Using stick electrodes requires the least amount of equipment and provides maximum flexibility for welding in remote locations and all positions.
Alloy availability - most hard facing alloys are available as covered electrodes.
Material thickness - within certain practical and economic limitations, most parts can be welded with the MMAW process.
Welding position - hard surfacing covered electrodes are available for out-of-position work.
Versatility - covered electrodes are capable of being used out on deck and in remote locations.
Disadvantages:
Dilution: two or three layers are needed to obtain maximum wear properties.
Low efficiency/deposition - stub loss and deposition of 1 - 3 kg/h (2,2-6,6 lb/h).



EN ISO 4063: 114 Wire Welding using Flux-Cored Arc Welding (FCAW-S) self-shielded

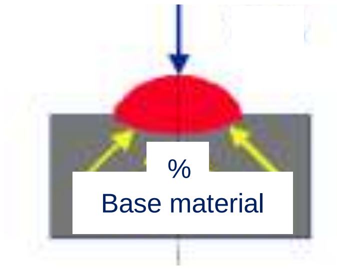
Advantages:
Alloy availability - almost as many alloys available as MMAW.
High deposition - rates ranging from 3,0 - 12 kg/h (6,6-26,4 lb/h). Flux cored wires increasing deposition rates over MMAW.
Deposit integrity - good recovery of elements across the arc.
Easy to operate - minimal time is required to train an operator.
Versatility - not as versatile as covered electrodes, but capable of being used on deck and in remote locations due to open arc operation.
Disadvantages:
Dilution: two or three layers are needed to obtain maximum wear properties.
Welding position - although some wires have out-of-position capabilities, most are designed for flat and horizontal applications.

Gas shielded wire welding methodes will requiere that welding locations are screened off from wind and draft.

Important details to take into consideration during welding

Dilution is the percentage of base metal that enters into the weld bead. The percentage of dilution will depend on the welding process and the heat input. This will to a large extent influence on the final weld deposit mechanical properties.

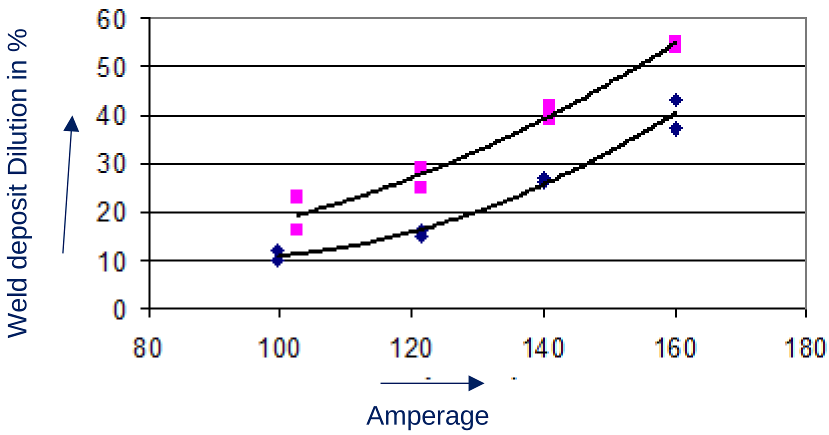
% Consumable



Arc Welding process	Dilution
MMAW Stick/Electrode	15-30%
Wire Welding using Self Shielded flux cored	15-35%
Wire Welding Spray arc	15-35%
Wire Welding Dip transfer	15-30%
Wire Welding Pulsed Arc Solid and Metal cored	5-15%
TIG Welding	5-15%

An other factor that will deside the percent dilution will be the amperage used for the specific welding process. As an exsample:

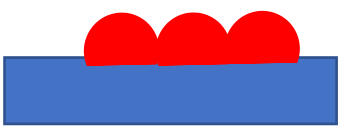
Weld deposit dilution for two different MMAW stick electrodes 3,2mm (1/8") depending on Amperage.



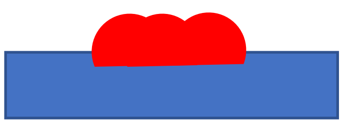
Too much dilution by the base metal can severely degrade the desired properties of the overlay. Therefore, do not use higher amperage than necessary to provide a sound weld. Multiple layers of overlay to get past the dilution, or an intermediate, buttering or "cushion coat" to block dilution will in some cases be necessary. Avoid excessive build-up of hard facing deposits or they may crack and break off rapidly in service. If thick deposits are needed, use the appropriate build-up materials before hard facing.

The following suggestions will help minimize dilution, resulting in greater wear resistance.

1. Do not use excessive welding currents.
2. Direct the arc towards the previous run rather than towards the base metal.
3. Use close overlap (50 to 75%) when placing weld beads side by side.



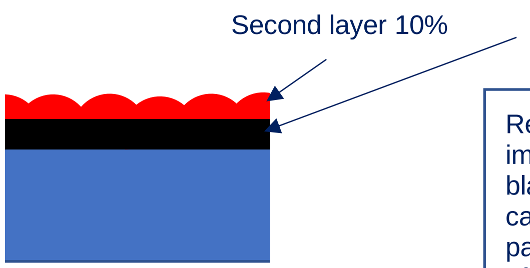
Incorrect 30 % dilution



Correct 10% dilution

4. Use DC positive polarity to electrode (reverse polarity) or follow the electrode manufacturers recommendations.
5. Do not use excessive preheat. Preheat with recommended ranges.
6. Regardless of stringer or wide weave beads, the travel speed should be adjusted to direct the arc on the weld puddle.
7. When using wire welding processes, a longer stick-out will reduce penetration.

Expect that there will be at least 20-30% dilution in the first layer depending on amperage setting using MMAW.
In second layer the dilution with the base material will be down to approximately 10%.



Regarding carbides in matrix alloys: Fine particle impingements like sand at high speed, like in sand blasting, can create big wear problems. Never use carbide products in this kind of application. The fine particles of sand will wear out the soft matrix instead of the carbide. Keep to max two layers of carbide bearing products. This to avoid spalling.

General welding procedures

Remove rust, dirt, grease, oil and other contaminants from the surfaces to be welded.

A sound base is required, and this may necessitate removing fatigued or rolled over metal, high ridges or other major surface irregularities. This may be done by Air Carbon Arc gouging (ACA) , grinding or machining. Cracks in the base metal should be ACA gouged or ground out and repaired using compatible electrodes. If cracks are through the base metal make sure the end of the crack is removed by drilling or cutting at the end before gouging out the cracks.

Previous hard face should be removed if:

- The type used is unknown.
- The type used is incompatible with the new deposit.
- Deposits are porous or contain voids.
- Deposits are badly cracked and deformed.
- If the surface is severely work-hardened, about 3mm (1/8") of work hardened surface should be removed before hard facing or build-up of a worn area.

Failure to do so might result in weld bead spalling.

Edges should be rounded, no sharp edges. This causes excessive mixing of the base metal and hard facing alloy. If a build-up is needed prior to hardfacing, select a build-up that is compatible with the base metal composition. Never use AWS E-7018 electrodes as a build-up or buttring layer. It does not have the hardness and strength for hard facing applications.

Deposit Thickness — Avoid excessive build-up of hard facing deposits or they may crack and break off rapidly in service. If thick deposits are needed, use the appropriate build-up materials before hard facing. Unless an alloy has been specifically designed and tested for multi-layer weld overlays, the following guide lines should be useful to determine the number of hardface layers that should be applied.

Number of layers depending on the welding deposit hardness

Deposited Hardness of Overlay HRC*	Maximum Layers
65 or higher	1-2
50-64	2-3
40-50	3-5

*Hardness Rockwell C (HRC)

Regarding 11 - 14% manganese steels: These appear in many respects to be similar to mild steel or low alloy steels and are difficult to distinguish by normal visual inspection, file tests and spark tests. Their main feature is that they will not be attracted by a magnet. Hence, any doubtful steels should be checked with a magnet and, if they are not strongly attracted, treated as manganese steels. For metal identification go to: www.teandersen.com> Welding Library >Technical Update: Methods for identifying Metals & Recommendation for Welding.

Preheat and Interpass Temperature

The combination of alloy content, carbon content, massive size and part rigidity creates a necessity to preheat in many build-up and hard facing operations. Slow cooling may also be needed.

Manganese steel: Use ony low or minimum preheat, low heat input, and low interpass temperature. Caution — Manganese steel becomes brittle if overheated. While a 93 °C (200°F) preheat may be required, do not allow interpass temperatures to exceed 260°C (500°F).

Some alloy steel components require a specific heat treatment to perform properly in service. This must be considered when preheating and welding. Contact the part maker for information. If no information availabl:
Carbon and certain alloying elements, determine the preheating temperature. Their combined effect is given by the “carbon equivalent” (Ceq) as follows:

$$Ceq = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

Mn: Mangan, Cr: Crhomium, Mo: Molybdenum, V: Vanadium, Ni: Nickel, Cu: Copper.

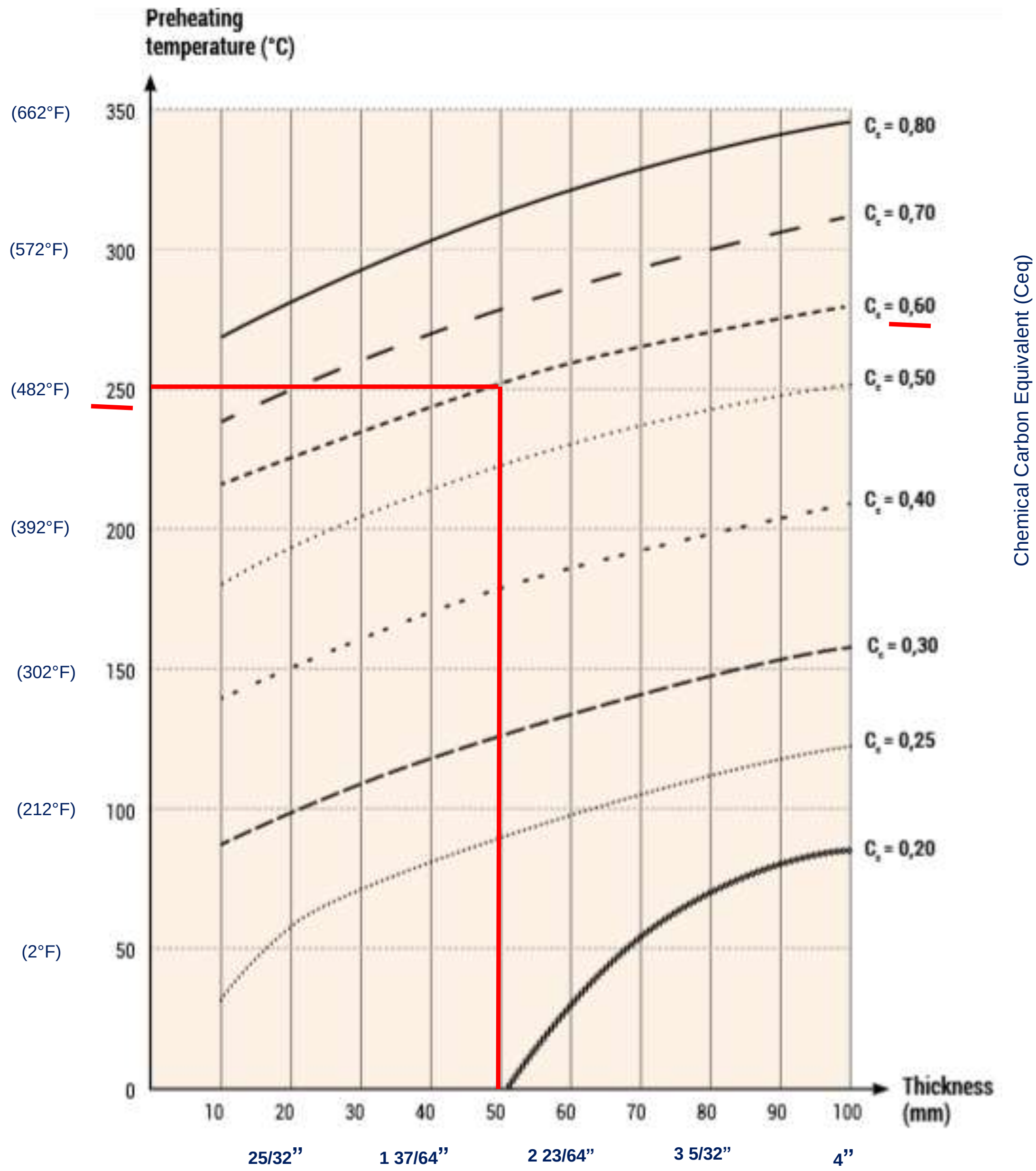
Preheating temperature depending on base materials carbon equivalent (Ceq)

Carbon equivalent	Weldability	Preheating	Postheating
Ceq < 0.35	Good	Light preheating	Not requiered
0.35 < Ceq < 0.6	Acceptable	150-250°C (302-482°F)	Preferably
Ceq > 0.6	Precautions requiered	>250°C (482°F)	Requiered

As hardfaced layers are not ductile, shrinkage cracks frequently appear. To minimise cracking, the nature of the consumable/ filler metal also needs to be considered.

In certain cases, even if the base metal has a Ceq<0.35, the use of a cobalt base hardfacing requires a minimum preheat of 300-350°C (572-662°F). In addition, to avoid cracking in the deposited metal, slow cooling is required (typically less than 50°C (122°F) per hour).

After having calculated the carbon equivalent (Ceq) based on the base materials chemistry we also have to take the base material size and part rigidity into consideration.



A base material with Ceq 0.60 and 50mm (2") thickness will need to be pre heated to 250°C (482°F)

Hard facing of cast iron:
Hard facing of cast-iron require a special welding procedure. Nickel and nickel-iron products usually are suitable for rebuilding cast iron. These products are not affected by the carbon content of the parent metal and remain ductile. Multiple layers are possible. If further wear protection is required, metal carbide products can work well on top of the nickel or nickel-iron build-up.

For further information go to: www.teandersen.com> Welding Library > Welding of Cast iron.

General wear problems onboard ships

Ship's Mooring Equipment

Deck equipment like anchor and mooring gear often have significant damage and scoring caused by the repeated wear and abrasion / adhesive (metal-to-metal wear) from handling chains and wire rope. These adhesive wears can damage or significantly reduce the life expectancy of the equipment itself and the rope and / or the chains it is to handle.

Typical deck equipment that is found to have wear damage from rope and/ or chain:
Mooring drum, guide roller, warping head, bollard, mooring pipe / hawsehole, windlass gypsy wheel / wildcat.

Anchor and mooring combined windlass/mooring winch

Welding Procedure for repair of winch wheel pockets

The information in this procedure must be followed closely if the desired results is to be obtained.

General information:

The safety of ships and semisubmersible oilrigs depends on faultless anchoring. This means that winch wheels and anchor chains have to be in good condition.
Onboard ships the winch wheel is referred to as the gypsy wheel located in the anchor windlass. On large tankers and cruise ships, the windlass may be split into independent port and starboard units. Semisubmersible rigs normally have 2 to 3 anchor winches with chains and anchors at each corner, making a total of 8 to 12 winches on one rig. This keeps the ship or rig in position during anchoring or for semisubmersible during operation.

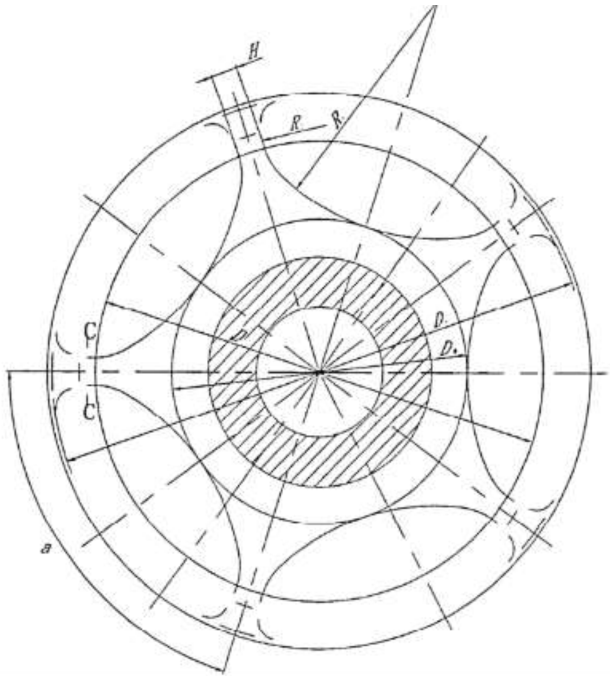
When the rig arrives at the location for operation, one anchor is lowered from the rear and is taken by anchor handling vessel to its position approximately1500m from the rig. The vessel then takes an anchor from the opposite end of the rig, brings it out 1500m and drops it. This operation is repeated for all the anchors. Pulling the chains along the sea bottom will create too much resistance so the anchor chain is kept from touching the sea bottom by keeping a tension on the chains by means of the anchor winches.
The anchor handling places extreme wear and pressure on the winch wheel - pockets where the chain touches the winch wheel. In addition to metal to metal friction, the pockets are subjected to impact and corrosion. The impact is caused by the high speed of the chain up to 300m/min and the corrosion is caused by the seawater.

Dimension of the chain links are:

Length	470mm+/-5% (18½")
Diameter	76-84mm (3- 3 5/16")
Weight approx.	40-50Kg (88-110lb)

There are mainly two types of chain used on oil rigs and the difference lies in toughness and hardness.
The hardness is 200-220HB for ORQ, NV-K3 and RQ3 grades of chain, and 300-320 HB for NV-K4, RQ4 grades of chains.

The contact surface chain-link-winch wheel pocket is approx.18-20mm2 (45/64-25/32") per link. The wear on the winch wheel pocket are created during time of operation and depends on the number of anchor handlings. Experience shows that between 2,5-5 years of approx. 8 anchor handlings is the normal between repair of winch wells, depending on type of operation and weather conditions, and also on conditions in the area in which the rig is operating.



The winch wheels are normally made of cast steel grade 45/3 or 52/3. However, other materials are also found in the market. The wear shows that the wheels have high elongation with too low yield point witch result in unacceptable deformation. The wheels manufactured in Norway today are welded at the factory following the procedure described herein. High elongation combined with sufficient surface hardness and low coefficient friction is of the utmost importance for the lifetime of the winch wheel.

Two types of welding consumable have been developed especially for this type of wear. The characteristics of the weld metal are:

-It must have high yield point.
-Deformation hardening that keeps its elongation.
-A lower coefficient of friction than the base material in order to avoid wear.
-The possibility for welding on steel with high carbon equivalent without reduction in elongation.

1. Identify base material:

The first step is identifying the winch wheel base material. The most common material in winch wheels on oilrigs is cast steel of the following qualities:
-DIN 1861-GS 45/3
-DIN 1861-GS 52/3
-DIN 25CrMo4V

The most common one is GS 52/3. This should be informed by the ship / rig owner or by winch manufacturer. If the identity of the base material is not confirmed it is necessary to make a chemical analysis. The hardness of the wheel is approx. 130-190HB.
Preheating of the base material can sometime be difficult due to weather conditions and technical possibilities. It is strongly recommended to follow the preheating temperature on the material 25CrMo4V which is 150°C (302°F). The preheat on 45/3 and 52/3 is 50-100°C (122-212°F). The heating shall be performed on the surface in the pockets of the wheels.

As mentioned previously, onboard ships the winch wheel is referred to as the gypsy wheel (UK) or wildcat (US) located in the anchor windlass. The wheel itself will in most cases be made from low alloyed cast steel ZG 35Mn or similar. There will be much less wear on a ship's gypsy wheel compared to a semisubmersible rig anchor winch wheel.

Standard IB/T 6402 ZG 35Mn

Chemical composition:

Carbon	0,3-0,4%
Silicon	0,6-0,8%
Manganese	1,10- 1,40%
Phosphor	0,035% Max
Sulphur	0,035% Max
Hardness	150HB

Do not attempt welding repair if gypsy wheel is made from cast iron.

2. Identify Chain grade:

Depending on working conditions in service different ships / rigs are using different chain grades. These are recognised by the different classification societies. The chain grades are as follows:

American Petrolium Inst. (API)	
Grade	-ORQ
DNV/GL	
Grade	-NV-K3
Grade	-NV-K3 RIG
Grade	-NV-K4 RIG
ABS	
Grade	-RQ3
Grade	-RQ4
LR	
Grade	-U3

When reconditioning the pockets, the strength and hardness of the chain is an important factor. Chains will mainly be of one of the two following hardness's:

Hardness	Chain grade
200-220HB	ORQ
	NV-K3
	NV-K3 RIG
	RQ3
	U3
300-320HB	NV-K4 RIG
	RQ4

The welding procedure is different for each of these main types of chain grades.
Procedure 1 is developed for 200-220HB
Procedure 2 is developed for 300-320HB

3. Winch wheel pocket shape:

It is of great importance to restore the pocket on the winch wheel to right shape after repair welding. This in order to prevent damage to the anchor chains during normal operation. The method of getting back to normal shape is to make a template. This template shall be a piece of sheet metal that should fit to the pocket on the edges towards the centre space between the winch wheel flanges. The template must be made from an undamaged pocket or supplied by the winch wheel manufacturer.

Place the template on the chain wheel and mark the repair area.

Marking template for pocket.

4. Calculating welding consumable.

By experience we know it is difficult to calculate the correct amount of welding consumable. This is because it is impossible to know in advance how deep it will be required to cut to get rid of the tired material in the pockets. This you will of course know when you are ready to start welding, but to help you on the way we know by experience that each pocket for 76mm (3”) chain requires approx. 8Kg of consumables. There are 5 pockets on each wheel. This value depends on the condition of the pockets, if they have been repaired previously, and how this has been done. To help calculating, one can use a simple formula like the following:
Count the areas that require repair on all the winch wheels. Measure the area in cm^2. Measure the thickness of the damaged area in cm. Put these values into the following formula:
Area in cm^2 X Thickness in cm^2 X 7,87 (grams) X number of pockets = consumables required.

5. Preparation before welding.

All welding shall be performed under dry conditions. In case of bad weather, the worksite must be covered to obtain the correct conditions.

6. Preparation of base material.

-Cut away all worn base material and old weld metal by air carbon arc gouging (ACA).
-Grind the whole area free of grooves, holes, spatter, etc.to at least 1mm below the surface of the ACA gouging, this in order to remove carbon remains.
-Examine the entire area for cracks, using dye penetration method or other means. Never use magnetic powder method for crack detection on stainless steels in combination with steel.
- If any cracks, they should be removed by further gouging followed by grinding.
- Examine for cracks.

7. Preheating.

Preheating of winch wheels is difficult to perform due to large size of base material and the outdoor welding conditions. The two normally used base materials GS45/3 and GS52/3 have good weldability. The recommended preheating temperature is approx.50-100°C (122-212°F) using oxy acetylene or oxy propane torch. GS 25CrMo 4V is more sensitive to welding and preheating of minimum 150°C (302°F) is recommended. This material is however used on few rigs. Interpass temperature (temperature during welding) should not exceed 250°C (482°F) for neither of the welding procedures.

8. Welding procedure:

Procedure 1.

For use on winch wheels fitted with chains of grades ORQ, NV-K3, NV-K3 RIG, RQ3 and U3. All with chain hardness of approx.200-220HB.

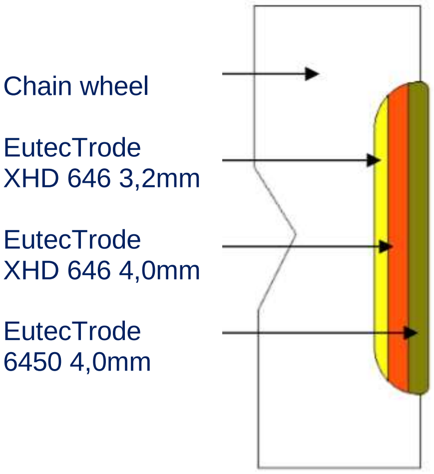
-Welding position should be horizontal or vertical approx.45 deg.
-Welding first layer:
Use electrode Eutectrode XHD 646 3,2mm (1/8”) Alternative TeroMatec3302*.
Amperage: 130-160 Amp DC+.
-Weld single beads, do not weave during welding, use previous bead as a heat buffer. Cover the whole area with first layer.
-In case of heavy build up:
Use electrode Castolin XHD 646 4,0mm (5/32”).
Amperage: 180-230 Amp DC+ for the following layers.
-Use template to control that the right thickness is reached. Achieve approx. 1-2mm oversize, before grinding.
- Check that interpass temperature do not exceed 250°C (482°F).
- Grind to remove superfluous material and smoothen the surface. Warning: If the surface is not smooth after grinding the chain may be damaged when the winch is operating.
- Examine the entire area for cracks, using a dye penetrant crack detector. Remember never to use magnetic penetrant methods for crack detection on stainless steels in combination with carbon steel.

Procedure 2.

For use on winch wheels fitted with chains of grades NV-K4 RIG, RQ4 and U3 all with chain hardness of approx.300-320HB.

-Welding position should be horizontal or vertical approx.45 deg.
-Welding first layer:
Use electrode Eutec Trode XHD 646 3,2mm (1/8”)
Amperage: 130-160 Amp DC+
-Weld single beads, do not weave during welding. Use previous bead as a heat buffer. Cover the whole area with first layer.
-In case of heavy build up:
Use electrode Eutec Trode XHD 646 4,0mm (5/32”).
Amperage: 180-230 Amp DC+ for the following layers.
Weld two last layers with electrode EutecTrode 6450 4,0mm (5/32”) Alternative: TeroMatec 3205*
Amperage: 150-180Amp DC+.

* TeroMatec3302 and TeroMatec 3205 are flux cored wires used in Flux Cored Arc Welding Self Shielded (FCAW-S). By some referred to as Open Arc. No shielding gas is needed.



-Use template to control that the right thickness is reached. Achieve approx. 1-2mm oversize, before grinding.
- Check that interpass temperature do not exceed 250°C (482°F).
- Grind to remove superfluous material and smoothen the surface. Warning: If the surface is not smooth after grinding the chain may be damaged when the winch is operating.
- Examine the entire area for cracks, using a dye penetrant crack detector.

9. Consumable

The electrodes recommended for this wear are a type of stainless-steel work hardening austenitic alloy, which hardens under the pressure from the chain. It is of great importance that the overlay is not too hard, as this can result in wear on the links. The electrode has an austenitic structure as welded, and the surface increases in hardness by being transformed to martensitic structure. This work hardening is caused by the chain when the ship / rig is handling her anchors. The high hardness is approx. 1-2mm deep, but can reach deeper on old and heavily deformed overlays. When repair welding takes place this old and hard overlay has to be removed down to the base material. Important: Do not weld on work- hardened, old overlays.

EutecTrode XHD 646
Main Application: Impact
Secondary Application: Friction
Ideal for buttering layers and rebuilding hardenable alloy steel or 13% manganese steel.
-Remarkably easy to weld even in contact
-High work-hardening rate
-Resistant to hot cracking
-Corrosion resistant welds
-Thick multipass capability
-High metal recovery ~150%
-Self-releasing slag
-Smooth even beads
-Machinable with tungsten carbide tip tool
Hardness as welded: 190HB 180HV30
Hardness work hardened: 415HB 400HV30

Classification:
DIN 8555: E8-UM-200-400-CKZ
DIN EN 14700: E Fe 10
AWS A 5.4: ~E 307 - 26
EN ISO: 3581-A: E 18 8 Mn R 53
DIN: W.Nr. 1.4370
DIN 8556: E 18 8 6 Mn R 26

EutecTrode 6450
Main Application: Impact, Friction
Secondary Application: Cavitation, Corrosion
-Highly resistant to pressure and impact wear
-Good work-hardening characteristics
-Machinable with standard cutting tools
-Allows contact welding
-Easy slag removal
-Non-magnetic, corrosion-resistant deposit
-High metal recovery ~150%
Hardness as welded: 240HB 250HV30
Hardness workhardened: 415HB 420HV30

Classification:
DIN 8555: E 7-UM-250 KPR
DIN EN 14700: E Fe 9
AWS A5.13: E Fe Mn Cr

The Eutec Trode XHD 646 proves too soft for the chain grades NV-K4 RIG, RQ4 and U3. The EutecTrode 6450 alloy with higher initial hardness is a better choice for this grade. This is the reason for two different procedures.

Alternative electrodes from other suppliers/ manufacturers:

Castolin	Capilla	Voestalpine Bohler UTP	Esab	Wilhelmsen Ships Service	Certilas
EutecTrode XHD 646 DIN 8555: E8-UM-200-400-CKZ DIN EN 14700: E Fe 10 AWS A 5.4: ~E 307 - 26 EN ISO: 3581-A: E 18 8 Mn R 53 DIN: W.Nr. 1.4370 DIN 8556: E 18 8 6 Mn R 26	**51 W** DIN 8555: E8-UM-250-CKPR DIN EN14700: E Fe 10-200/400-CNZ AWS A 5.4: ~ E 307-26 EN ISO 3581-A: E 18 8 Mn R 52 DIN: W.Nr. 1.4370	**UTP 63** DIN EN 14700: E Fe 10 EN ISO 3581-A: E 18 8 Mn R 32 DIN: W.Nr. 1.4370	-	**Unitor Wearmax 327** AWS A 5.4: ~E 307 - 26	**4370 HLS** AWS A 5.4: ~E 307 – 26 DIN: W.Nr. 1.4370 EN ISO: 3581-A: E 18 8 Mn R 26 DIN 8556: E 18 8 6 Mn R 26
EutecTrode 6450 DIN 8555: E 7-UM-250 KPR DIN EN 14700: E Fe 9 AWS A5.13: E Fe Mn Cr	**CR MA 47** DIN 8555: E7-UM-250-K DIN EN 14700: E Fe 9-250/450-cknp	**BMC** DIN8555: E7-UM-250-KPR DIN EN 14700: E Fe 9	**OK 86.30** DIN 8555: E7-UM-200-KR/D4 DIN EN 14700: E Fe 9	-	**(Ceweld) Dur MnCr** DIN 8555: E 7-UM-250-K DIN EN 14700: E Fe9 AWS A 5.13: E FeMnCr

Other wear locations on deck equipment:

Hawsehole with abrasive wear from rope.

Fairlead / guide roller with abrasive wear from rope.

Hawsehole with adhesive (metal-to-metal) wear from wire.

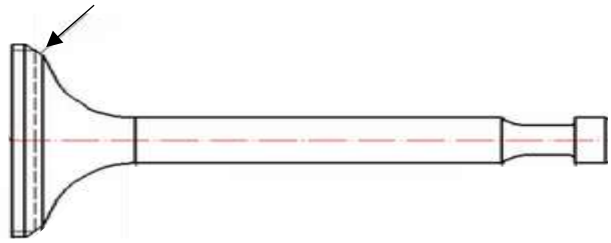
Wear on bollards.

Hawsehole anchor chain wear.

Engine parts

Working environment of Exhaust valves is extremely severe, the highest working temperature can reach to 800-900℃(1472-1652ºF). Engine valve will generate and bear huge shock load when it connects with valve seat. It also needs to bear high speed washing from flue gas. In this harsh working environment, engine valve will always meet situation of deformation, corrosion, burning loss and seat wear. So, Corrosion, Heat and Impact in combination.

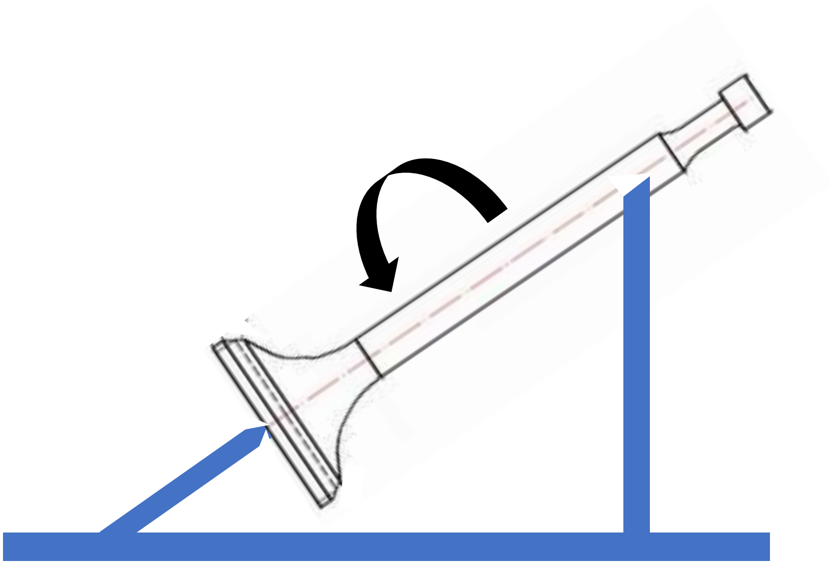
Conical surface with cobalt inlay



Exhaust valves can be made from different types of metals. High-grade stainless steel is often used. Along the rim, there will be an inlay of Stellite. This is a trade name. The alloy consists mostly of cobalt (Co) that is wear resistant at high temperature. Despite this, the wear and tear gradually do its work and leakages and blowholes start to develop.

1. Machine preparation
Align the spindle in a lathe and turn a suitably wide and deep groove in the hardened face to remove all old stellite down to clean, pure base material. Make room for at least two layers of weld metal, in order that the second (top) layer shall be near to pure weld metal with as little as possible of elements from base material mixed into it. Grove should have rounded inside corners to avoid slag inclusions. The use of crack indicator is very important at this stage in order that the weld is not put on top of undiscovered crack in the base material.

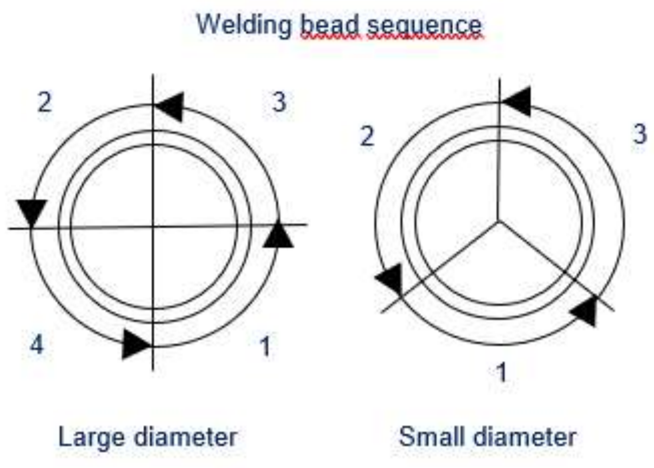
2. Weld preparation
Welding should as far as possible be carried out in the horizontal position. A suitable jig should be prepared, holding the spindle in a tilted position allowing it to be rotated.



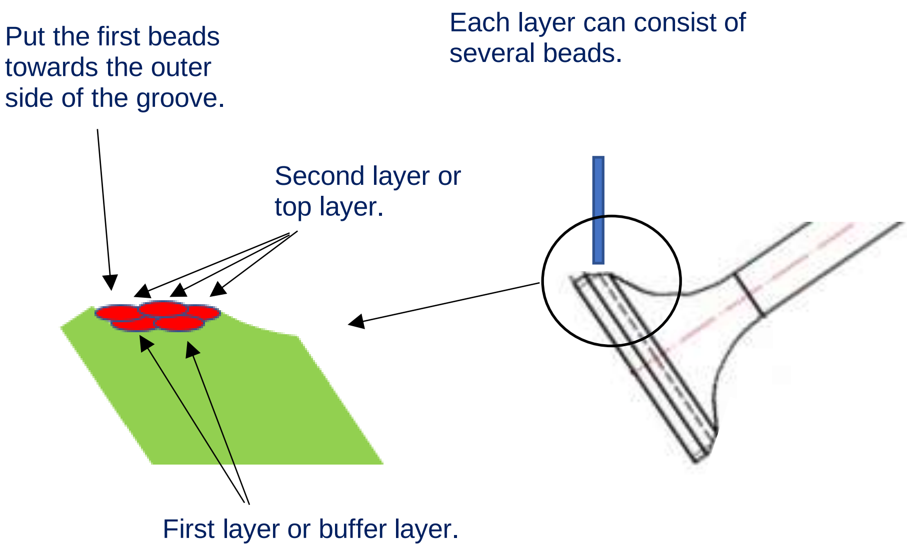
2. Weld preparation
Welding should as far as possible be carried out in the horizontal position. A suitable jig should be prepared, holding the spindle in a tilted position allowing it to be rotated.

3. Preheating
Preheat the valve head evenly to 50– 200ºC (122-392ºF) and maintain this temperature during welding. NB. Preheating temperature depending on type of alloy in the valve.

4. Welding
Electrodes should be dried at 250ºC (482ºF) for 1 hour prior to use. Weld using + polarity to the electrode holder and an amperage of approximately 110 Amp. Keep the arc short and hold the electrode as near as possible to 90º to the work piece. In order to minimise heat effects, the welding should be done in stages. Place the first bead towards the outer side of the groove, and do about one third of the circumference. Then start at the opposite side and do the second bead so it finishes where the first one started. Finally do the third, starting where the first one finished. For large diameter spindles, the bead should be done in four parts.



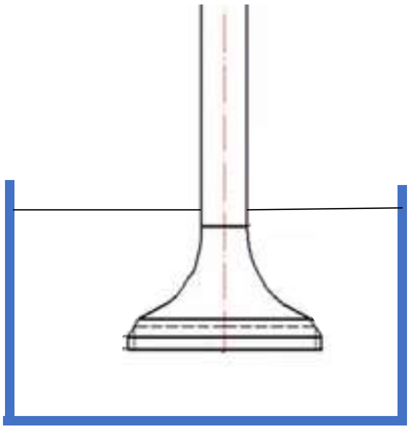
Grind the starting and stopping point of each bead. Also grind the bead itself to remove possible slag and spatter, in order to obtain a smooth transition between beads. Control the temperature adjacent to the welding zones and do not start the next bead until the base metal has regained the correct temperature.



Type of electrode to use to be according to:
DIN 8555: E 20-UM-250/300-CRTZ DC
DIN EN 14700: E Co1
AWS A5.13: ECoCr-E

DC+ 3,2mm (1/8") 70-120 Amp
Cobalt (Co) Rest
Chromium (Cr) 20%
Wolfram (W) 15%
Nickel (Ni) 10%
Manganise (Mn) 1%
Silicon (Si) 0,8%
Ferrum (Fe 2%)
Carbone (C) 0,1%
Resistance to thermal shock
Good resistance to oxidation
Hot crack-resistant
Good work-hardening characteristics Hardness ~250 HV30 (as deposited) ~440 HV30 (work-hardened) 25HRc -42HRc
Machinable

Castolin: EutecDur 9025N (DIN EN 14700: ECo1, AWS A5.13: ECoCr-E, DIN8555: E20-UM-300-CKTZ)
UTP Celsit 721 (DIN EN 14700: ECo1, AWS A5.13: ECoCr-E, DIN8555: E20-UM-300-CKTZ)
Wilhelmsen Ships Service: Unitor Impact -329S (DIN 8555: E 20-UM-250-CRTZ)



5. Cooling
When the top layer is completed, the spindle should be immersed in insulating material or dry sand in order to ensure slow cooling.

6. Final machining
After cooling, machine to correct tolerances, use tool bit quality H1 or K10 with negative 4º cutting angle, low turning speed and fine feeding.

NB. Newer designs valves can be made of nimonic metal. Nimonic is a registered trademark of Special Metals Corporation that refers to a family of nickel-based high-temperature low creep superalloys. Nimonic alloys typically consist of more than 50% nickel and 20% chromium with additives such as titanium and aluminium.

Other application for use of this type of electrodes onboard: Pump parts, Valve parts and Rocker arms.

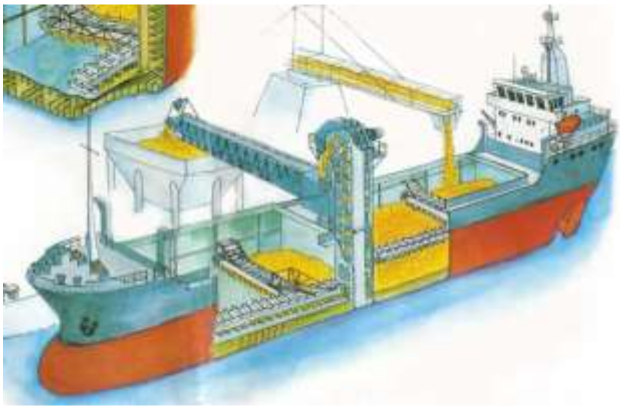
Ships with special wear problems

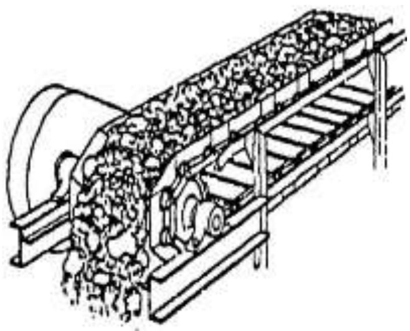
Bulk carriers

Bulk carrier, bulker is a merchant ship specially designed to transport unpackaged bulk cargo, such as grains, coal, ore, steel coils and cement, in its cargo holds. Today, bulk carriers make up 21% of the world's merchant fleets. Bulk carriers can be gearless (dependent upon terminal equipment) or geared (having cranes integral to the vessel). Bulk cargo can be very dense, corrosive, or abrasive.

Geared bulk carriers are typically in the handysize to handymax size range although there are a small number of geared panamax vessels, like all bulk carriers they feature a series of holds covered by prominent hatch covers. They have cranes, derricks or conveyors that allow them to load or discharge cargo in ports without shore-based equipment. This gives geared bulk carriers flexibility in the cargoes they can carry and the routes they can travel.

A **self-discharger** (or **self-unloader**) is a ship that is able to discharge its cargo using its own gear. The most common discharge method for bulk cargo is to use an excavator that is fitted on a traverse running over the vessel's entire hatch, and that is able to move sideways as well. Lake freighters on the Great Lakes use conveyor-based unloading gear to empty funnel-shaped holds from the bottom, lifting the bulk cargo onto a boom.





Excavator bucket

An excavator bucket is mainly exposed to two types of wear: sliding abrasive wear, and impact wear.

When handling rocks or gravel, it's usually a mix of both types. Bucket's structure can in some cases be made of a relatively mild steel, such as A36, grade 50, A514 or S355. If exposed to abrasive materials, the service life will be short and costs for repair and downtime will be high. To increase service life, the mild steel buckets can be "beefed up" with wear-resistant components – a wear package for protection (wear Strips can be used inside and outside of excavator and loader buckets). This kind of bucket has a lot of deadweight in the structure due to the combination of mild steel and additional wear parts. A bucket with all of its main components – floor, shell, side sheets, cutting edge, side cutters, cheek plates, wear bars and wear plates – made of a wear-resistant steel such as for example Hardox 450 will be both strong and light. It will also outlast buckets with lower-grade steel several times.

MMAW Electrodes for Bucket lips and teeth rebuilding

<table>
<tr><td rowspan="2">Type of Tooth base material</td><td rowspan="2">Build-up material</td><td>Dirt or clay</td><td>For sand</td><td>For rock, slag and dirt</td></tr>
<tr><td>Abrasion</td><td>Severe Abrasion</td><td>Abrasion and Impact</td></tr>
<tr><td>Manganese steel</td><td>DIN 8555:
E7-UM-250-KP
DIN EN 14700: E Fe9
Alternative:
DIN 8555:
E7-UM-200-KP
DIN EN 14700: E Fe9</td><td rowspan="2">DIN 8555:
E 10-UM-60-GRZ
DIN EN 14700: E Fe14</td><td rowspan="2">DIN 8555:
E 10-UM-60-GR
DIN EN 14700: E Fe15
Alternative:
DIN 8555:
E 10-UM-65-GRZ
DIN EN 14700: E Fe16</td><td rowspan="2">DIN 8555:
E 10-UM-45-GPZ
DIN EN 14700: E Fe14
Alternative:
DIN 8555:
E 10-UM-50-GPZ
DIN EN 14700: E Fe6
Alternative:
DIN 8555:
E 10-UM-60-GRZ
DIN EN 14700: E Fe14</td></tr>
<tr><td>Carbon or alloy steel</td><td>DIN 8555:
E 1-UM-350-GP
DIN EN 14700: E Fe1</td></tr>
</table>

Austenitic consumables (AWS 307 or AWS 309) shall always be used for welding manganese steel adaptors to Hardox cutting edges.
For detailed information on welding of Manganese steel go to www.teandersen.com>
Welding Library >Steels used onboard ships and how to perform maintenance welding.

Hard facing Patterns

Selection of the proper hard facing alloy and preparation of the workpiece are not enough to maximize the service life of a part. The pattern used to make the overlay must also be considered, as it too, will have a bearing on how long the part will last. There are times when putting less hard facing on a surface is better than covering the entire surface. There are a number of ways that stringer bead patterns are used depending on the service conditions of the component.

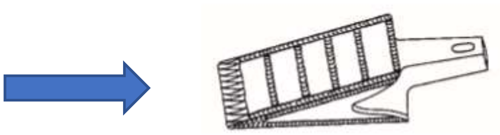
Sever abrasion

To counter severe abrasion, the hardfacing should be continuous across the whole of the surface concerned. This ensures that there is no contact between the external element and the base metal. In most cases, the weld beads are oriented in the same direction as the flow, thus allowing continuous passage of material.

Low or moderate abration

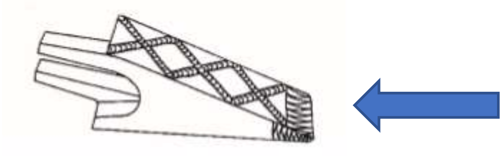
In case of low or moderate abrasion (without impact), surfacing may be limited to separated parallel beads. Spacing of the beads is a key factor that depends directly on the size of the abrasive. In case of high abrasion, the space between the beads should be reduced.

For Dirt, Clay or Sand plase beads perpendicular to material flow.



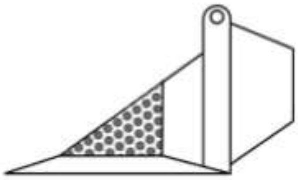
For Rock or Slag place beads parallel to material flow.

For both Rock, Sand or Dirt use waffle pattern.

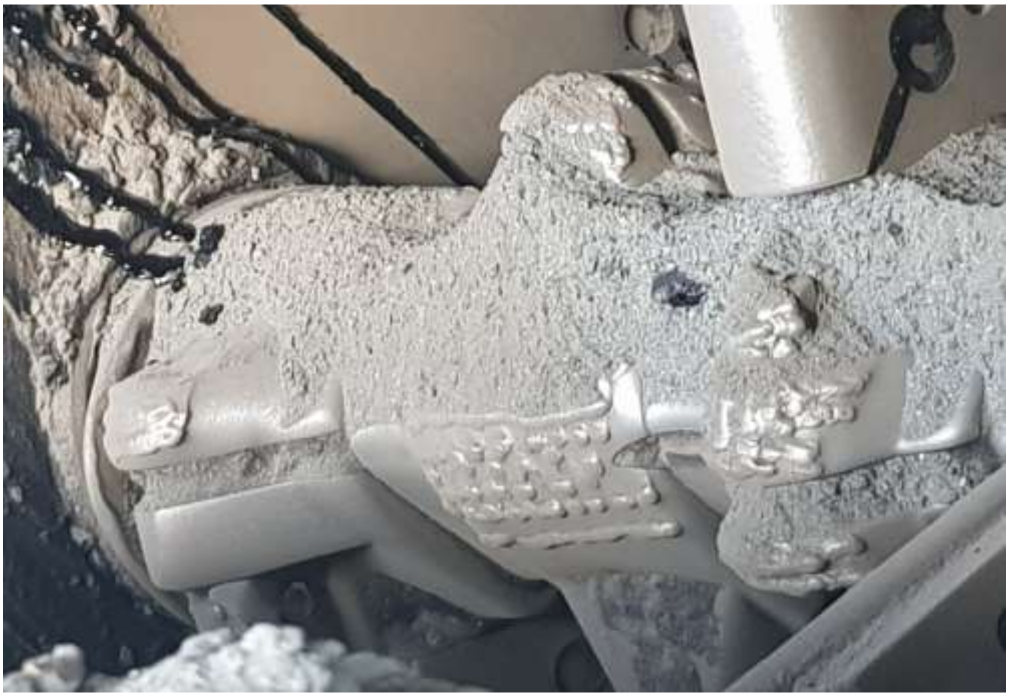


This type of pattern is widely used to combat abrasion involving large and small abrasives (e.g. sand with gravel and rock). The bead pattern causes the fine abrasive to lodge in the interstices, thus protecting the base metal from the larger abrasives (self- protection by clogging).

Spot welds (Low or moderate abrasion)



Spot welds is used when the base metal is sensitive to the heat input generated by the welding (e.g. manganese steels). The welding process implies starting the surfacing in the centre and working outwards. This will restrict the welding stresses and distribute them around the part in question.

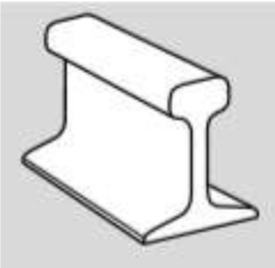


The interval between the spots depends on the size of the abrasive. The finer the abrasive, the smaller the distance between spots.

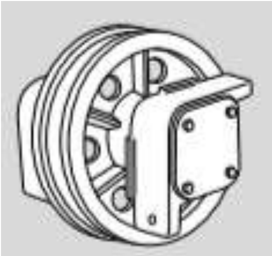
For Welding of cutting edge to bucket and adapters to cutting edge there are detailed procedures. If in need contact TE Andersen consulting.

Track way and crane wheels

Geared bulk carriers crane will in some cases have a rail trackway and crane wheels that can be in need of hard facing.



Manganese Steel	Carbon Steel
1.Grind off all work-hardened and fatigued base metal. 2. Weld using: DIN 8555: E 7-UM-200-KP Weave beads approx.19mm (3/4") wide. Skip weld to prevent build-up of interpass temp. Do not allow interpass temp. to exceed 260°C (500°F). Peen each bead. 3. Finish grind.	1. Grind off work-hardened and fatigued base metal. 2. Preheat to 425°C (800°F). 3. Weld using: DIN 8555: E 1-UM-250 Alternative: DIN 8555: E 1-UM-350-GP Weave beads. Overbuild to allow for finish grinding. 4. Post heat 600°C (1100°F) Cover for slow cooling.

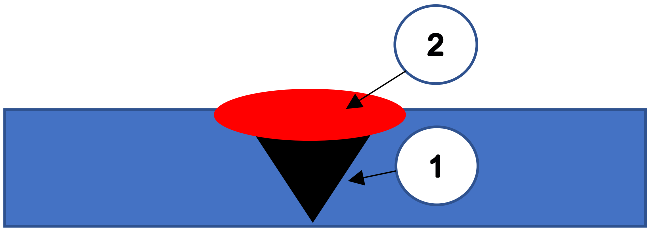


Crane wheels. Weld using electrode:
DIN 8555: E 2-UM-55-G
A preheat between 200-350°C (392-662°F) is necessary to prevent cracking with interpass temperatures of up to 400°C (752°F) in situations of high restraint and/or heavy thicknesses. After welding the component should be covered and slowly cooled. The deposited weld metal is not machinable by conventional methods although the deposit can be shaped by grinding.

Wear plates

To the extent possible vessels will make use of wear plates. The fastening of the plates can be done mechanically or welded on to the part in question. Hard facing welding of parts is more time consuming and will if not done properly and according to procedure give undesirable side effects.

Consumables for joining and protection of the joints



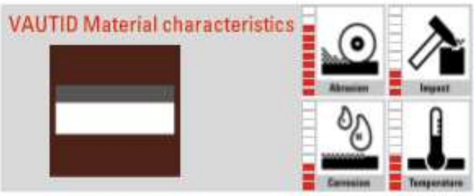
1) Joining of wear plates	2) Protection of joints	
	Wear resistant plates (Hardox*)	Composite wear plates (or hard faced plates)
A 5.4: ~E 307 - 26 EN ISO 3581-A: E 18 8 Mn R 53 DIN: W.Nr. 1.4370 DIN 8556: E 18 8 6 Mn R 26 Alternative: AWS A 5.11: E NiCrFe-3 EN ISO 14172: E Ni 6082 (NiCr20Mn3Nb) DIN: W.Nr. 2.4648 DIN 1736: EL-NiCr19Nb	AWS A 5.13: E FeCr-E4 DIN EN ISO 14700: E Fe16 DIN 8555: E 10-UM-65-Z	AWS A 5.13: E Fe5-R DIN EN ISO 14700: E Fe4 DIN: W.Nr.1.3348 DIN 8555: E 4–UM 60(65W)-ST

There are a large number of suppliers of wear plates. As an example: below find Vautid 100. It is a composite iron base chromium carbon alloy meant for severe abrasion and moderate impact with 62 HRC. There is a large area of application. The base material is structural steel with a 3 to 20mm hard surfacing layer depending on form of delivery. The plates can only be cut by the plasma cutter onboard.

VAUTID 100

Wear plate for highly wear resistant hardfacing

VAUTID



Base materials	All weldable steels, mostly structural steels
Material type Alloy components	High-chromium/ high-carbon alloy on iron base C – Cr – Fe
Recommended applications	In case of high abrasive wear and moderate up to normal impact up to 350° C
Weld deposit properties	Hardness (acc. DIN 32525-4): appr. 740 HV10, 62 HRC*
Main industries	Steel industry, cement industry, power stations, mining, sand and gravel industry, concrete industry, glass industry, recycling industry, timber wood industry, chemical industry, petrochemical industry, etc.
Typical machine parts	Chutes, screens, transfer units, bunkers, tubes, concrete mixers, mill linings, cyclones, seperators, bucket-wheel linings, excavator bucket linings, tractor shovel front edges, dust and ash ducts, fans, fan housings, etc.
Handling	- Conventional machining possible only by grinding - Thermal cutting using laser, plasma or water jet cutting - Cold working from diameter 300 mm possible with hard facing inside (1) - Cold working from diameter 450 mm possible with hard facing outside (1) - Fixing by welding or bolting on the base material - Constructions comparable with conventional steel construction

(1) dependent on thickness of plates

Forms of delivery

* subject to common industrial fluctuations

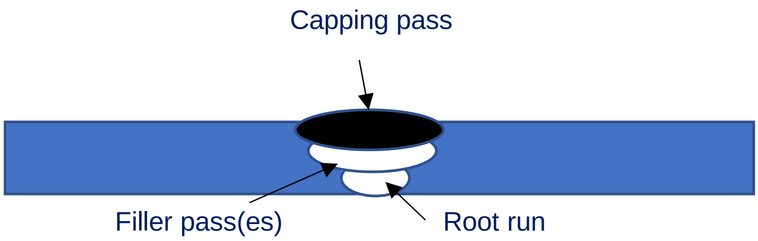
Formats (mm)	Thickness of the plates Base material + Hardfacing (mm)	Material Layers	Comments
Standard formats 2.400 x 1.150 (2) 2.900 x 1.400 (2)	3+3 (3), 5+3 (4), 6+4, 6+6, 8+5, 8+6, 8+8, 10+5, 10+10 further combinations on demand	≤ 6 mm: 1 Layer > 6 mm: 2 - 4 Layers	Base material ≤ 5 mm: Hardfacing 3 mm Base material 6 mm: Hardfacing 3 - 6 mm Base material ≥ 8 mm: Hardfacing 3-20 mm
Special body Up to 3.900 x 1.900 (2)	on demand	≤ 6 mm: 1 Layer > 6 mm: 2 - 4 Layers	Base material 6 mm: Hardfacing 4 -6 mm Base material ≥ 8 mm: Hardfacing 4 -20 mm

Hardox steel

Hardox steel is typically used onboard dredgers, bulk carriers and cement carriers that experience abrasive wear from the cargo they are processing and carrying. Often, a Hardox wear plate will be welded to a plain carbon steel structure only in the areas that experience abrasive wear. Since wear does occur, wear plates need to be replaced frequently, which makes this a very common welding application.

There are a number of different types of Hardox steel, ranging from Hardox Hi Temp, Hi Tuf, 400, 450,500,550, 600 and Extreme. The number indicate the approximate Brinell Hardness (HB)*. They are very wear resistant and contain from 0.25 to 0.80% Molybdenum (Mo), 0.10 to 2.5% Nickel (Ni), 0.10 to 1.5% Chromium (Cr) all depending on type of alloy.

To avoid weld cracking, the joint needs a welding procedure that need to be followed rather strictly. It is important to use an electrode with lower strength than the Hardox base metal for the root and filler passes, and then hard face only on the capping pass to obtain abrasion resistance of the weld surface.



Preheating and interpass temperature (temperature during welding) depend on type of Hardox and the plate thickness.

Maximum preheating and interpasss temperature

Hardox Hi Temp	300°C (572°F)
Hardox Hi Tuf*	300°C (572°F)
Hardox 400	225°C (437°F)
Hardox 450	225°C (437°F)
Hardox 500	225°C (437°F)
Hardox 550	225°C (437°F)
Hardox 600	225°C (437°F)
Hardox Extreme	100°C (212°F)

Interpass temperatures up to approx. 400°C (752°F) can be used in certain cases for Hardox Hi Tuf.

For further information on pre heating and interpass temperature go to:
www.teandersen.com>
Welding Library > Practical welding and cutting.
Technical update-The need for pre-heating when welding.
Technical update- Heat input and interpass temperature during welding.

Type of electrodes:
It is important to use an electrode with lower strength than the Hardox base metal for the root and filler passes, and then hard face only on the cover pass to obtain abrasion resistance of the weld surface. Unalloyed and low-alloyed electrodes with a maximum tensile strength of 500 MPa (72519 psi) are generally recommended for Hardox steel in general. Electrodes of higher strength max. 900 MPa (130534 psi) may be used for Hardox 400 and 450 in the thickness range 0.7 – 6.0 mm (0.028” – 0.236”).

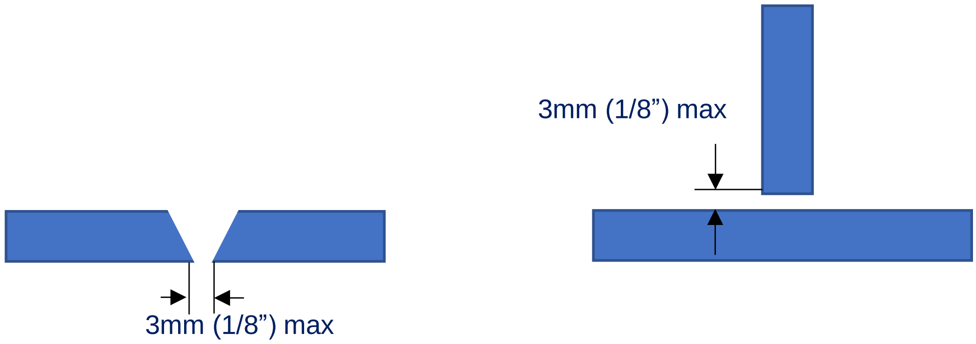
A better solution to consider:
Consumables of austenitic stainless steels can be used for welding all types of Hardox. They allow welding at room temperature 5 – 20°C (41 – 68 °F) without preheating, except for Hardox 600 and Hardox Extreme. The manufacturer of Hardox recommends giving first preference to consumables in accordance with AWS 307 and second preference to those in accordance with AWS 309. These types of consumables have a yield strength of up to approximately 500 MPa (72519 psi) in all weld metal. The AWS 307 type can withstand hot cracking better than AWS 309. Manufacturers seldom specify the hydrogen content of stainless-steel consumables, since hydrogen does not affect the performance as much as it does in unalloyed and low-alloyed consumables.

Electrode classification for joining and fastening of Hardox plates:

A 5.4: ~E 307 - 26
EN ISO 3581-A: E 18 8 Mn R 53
DIN: W.Nr. 1.4370
DIN 8556: E 18 8 6 Mn R 26

In general, about AWS 5.4 E307 electrodes: Joining of wear plates like Hardox to each other and to their supports. Welding of 14% Mn steel, armour steel, harden able steel and generally all hard-to-weld steels. Joining of stainless steels to carbon steels. Building up of rails and buttering layers before hard facing on 14%Mn steel or on steels of unknown composition or on carbon steels. An important electrode to have onboard a vessel.

Before tack welding, it is important to maintain a root opening between base plates not exceeding 3 mm (1/8”). Aim for as uniform a gap size along the joint as possible. Also, avoid weld start and weld stops in highly stressed areas. Make multiple smaller weld beads maintaining the base materials interpass temperature as mentioned above. If possible, the start and stop procedures should be at least 50 –100 mm (2” – 4”) from a corner. When welding to the edge of plates, a runoff weld tab (steel plate) would be beneficial.

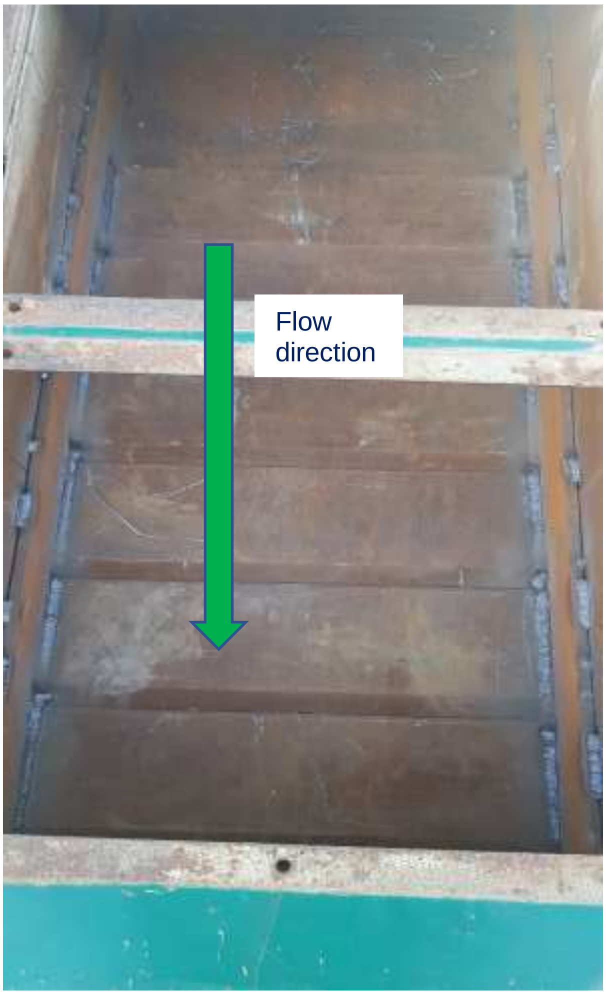


Use a symmetrical weld sequence.

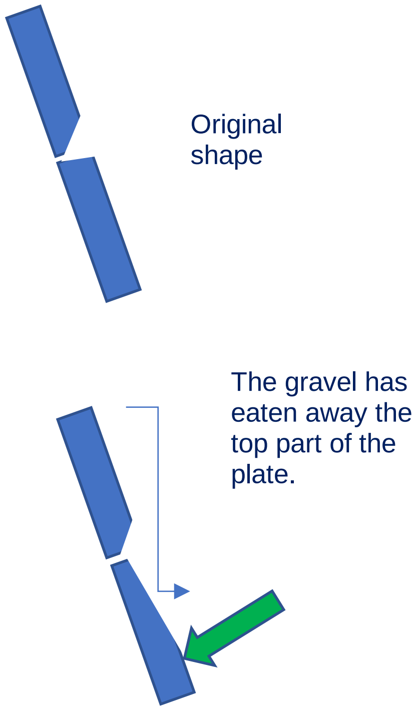
If the weld joint is located in an area with the expectation of high wear, one can employ hard facing with special consumables to increase the wear resistance of the weld metal.

Electrode classification for hard surfacing:

AWS A 5.13: E FeCr-E4
EN ISO 14700: E Fe16
DIN 8555: E 10-UM-65-Z



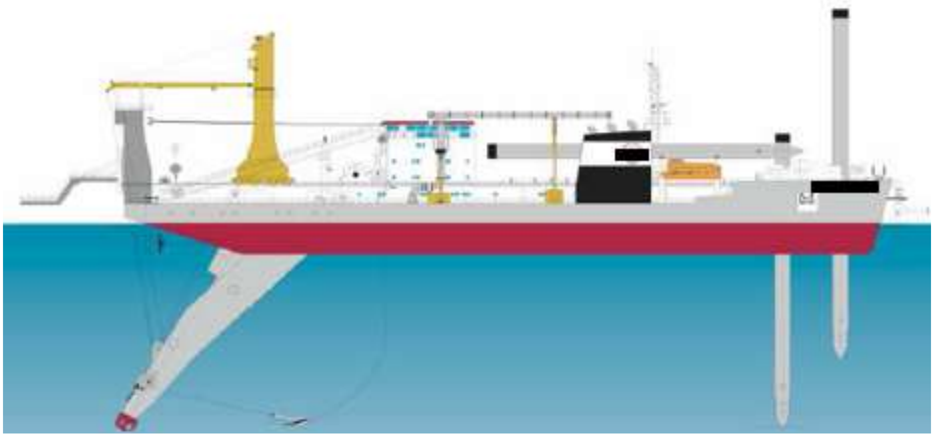
Hardox 500 plates welded into a steep shaft to stop wear.



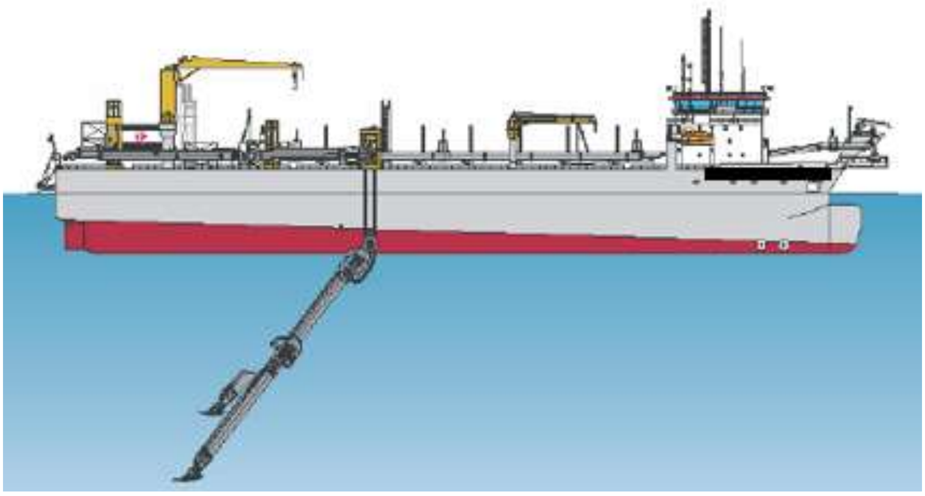
Dredgers

Dredging is the form of excavation carried out underwater or partially underwater, in shallow waters or ocean waters. It keeps waterways and ports navigable, and assists coastal protection, land reclamation and coastal redevelopment, by gathering up bottom sediments and transporting it elsewhere.

Cutting suction dredgers is equipped with a rotating cutter head, for cutting and fragmenting harder soils and rock. The material is sucked up by means of dredge pumps, and discharged through a floating pipeline and pipes on shore, to a deposit area.

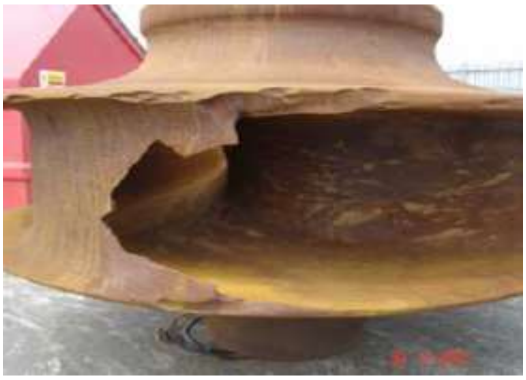


Hopper dredger trails its suction pipe when working. The pipe, which is fitted with a dredge drag head, loads the dredge spoil into one or more hoppers in the vessel. When the hoppers are full, the dredger sails to a disposal area and either dumps the material through doors in the hull or pumps the material out of the hoppers. Some dredges also self-offload using drag buckets and conveyors.



To the extent possible the dredgers will make use of wear plates. The fastening of the plates or bars can be done mechanically or welded on to the part in question. Hard surfacing welding of parts is more time consuming and will if not done properly and according to procedure give undesirable side effects.

Wear and tear on pump casings and impeller



Depending on type of vessel, wear resistant materials are chosen for the equipment in contact with soil, this allows for longer service life of the components:

Double walled dredge pumps, with hard cast-iron pump housing, special alloy impellers and wear plates are used for cutter dredgers, and the large hopper dredgers. On other vessels cast steel single walled pumps are installed.

Dredge pipes are lined with Ni-Hard*, or made of alloys with high resistance to abrasion for cutter dredgers and pipes in the pump room of large hopper dredgers (sometime in combination with FEDUR**). On other hoppers cast steel and rolled mild steel pipes are used.

Cutterheads designed for low maintenance: liners protect critical parts. The teeth system allows for easy and quick maintenance.

Drag heads protect with domite wear plates.

Rubber hoses: equipped with liners or special design.

* Ni- Hard= Cr 1,4% - 28% abrasive iron for low and high stress abrasion 400 to 750 Brinell.
** FEDUR= Composite steel of two layers. One layer with high weldability. The other hard carbon steel alloy of 910 HV (approx. 66HRC)

Suction mouth of a cutter dredger with domite laminated wear plates (700 HB-63HRC). Domite is a cast high carbon-molybdenum white iron on a backing plate of mild steel.

The following consumable chart gives suggested stick electrodes for Manual Metal Arc Welding (MMAW) according to DIN 8555 classification. The same chart can be used for Wire Welding process and tubular wires (metal cored or flux cored). Some of the symbols will however be different. An example:

An electrode according DIN 8555 for MMAW will read: E 10-UM-45-GPZ

Electrode Coated

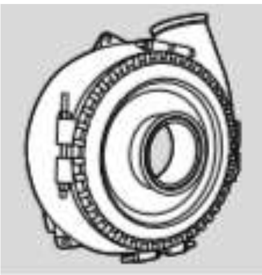
A tubular wire according DIN 8555 for wire welding will read: MF 10-GF-45-GPZ

Tubular wire, metal cored or flux cored Filled

<u>For Pump casings, Pump impellers, Side plates</u>

Dredge pump casings can be made from cast iron, manganese steel or carbon steel. Manganese and cast steel pumps can be rebuilt. Rebuilding of cast iron pumps must be avoided.

Classification	Build-up/buttering Base metal Carbon steel	Build-up/buttering Base metal Manganese steel	Hard facing
DIN 8555:	E 1-UM-250 E 1-UM-350-GP	E 7-UM-250-KP E 7-UM-200-KP	E 10-UM-45-GPZ E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-50-GPZ E 10-UM-60-GRZ



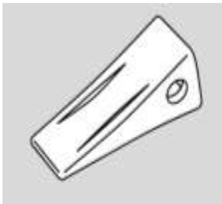
Pump casings:
Severe abrasion hard face using: E 10-UM-65-GRZ or E 10-UM-60-GR.
Moderate abrasion and moderate impact hard face using: E 10-UM-50-GPZ or E 10-UM-45-GPZ.

Pump impellers:
Severe worn manganese steel wanes rebuilding using: E 7-UM-200-KP.
Severe worn carbon steel wanes rebuilding using: E 1-UM-250 or E 1-UM-350-GP
Severe abrasion hard face with E 10-UM-60-GR or E 10-UM-65-GRZ

Side plates:
Rebuild worn seat areas of carbon steel using: E 1-UM-250
Rebuild worn seat areas of manganese steel using: E 7-UM-200-KP
Hard face with: E 10-UM-60-GR, E 10-UM-65-GRZ or E 10-UM-60-GRZ.

For Dredge Cutters head and Teeth

Classification	Build-up/buttering Base metal Carbon steel	Build-up/buttering Base metal Manganese steel	Hard facing
DIN 8555:	E 1-UM-250 E 1-UM-350-GP	E 7-UM-250-KP E 7-UM-200-KP	E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-60-GRZ



Depending on base metal build up with recommended consumable.
Hard face with: E 10-UM-60-GR or E 10-UM-60-GRZ.

Cutter head. The flared points overlaid with Wo carbides.

There are various tooth and cutting-edge systems on the market, each with its own advantages and disadvantages. They are all based on the principle that it must be possible to quickly replace the parts that are subject to heavy wear.

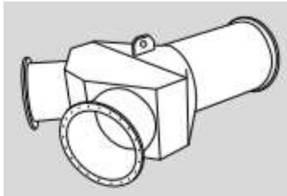
For Dredge Bucket Lips

Classification	Build-up/buttering Base metal	Hard facing
DIN 8555:	-	E 10-UM-45-GPZ E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-50-GPZ E 10-UM-60-GRZ

Severe abrasion: E 10-UM-60-GR
Abrasive wear and moderate impact: E 10-UM-50-GPZ or E 10-UM-60-GRZ

For Pipeline Ball Joints

Classification	Build-up/buttering Base metal	Hard facing
DIN 8555:	-	E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-60-GRZ



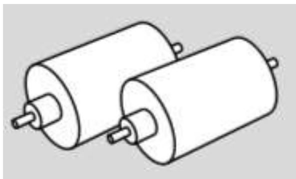
For Tumblers

Classification	Build-up/buttering Base metal Carbon steel	Build-up/buttering Base metal Manganese steel	Hard facing Base metal Carbon steel	Hard facing Base metal Manganese steel
DIN 8555:	E 1-UM-250 E 1-UM-350-GP	E 7-UM-250-KP E 7-UM-200-KP	E 2-UM-55-G	E 7-UM-250-KP E 7-UM-200-KP

Rebuild close to size by using appropriate build up consumable for carbon steel or manganese steel base material. Hard face manganese steel tumblers with E 7-UM-200-KP or E 7-UM-250-KP. Hard face carbon steel tumblers with E 2-UM-55-G

For Ladder Rollers

Classification	Build-up/buttering Base metal	Hard facing
DIN 8555:	E 1-UM-250 E 1-UM-350-GP	E 2-UM-55-G



Other Dredging parts

Parts	Build-up/buttering According to DIN 8555:	Hard facing According to DIN 8555:
Pipeline Swivels, Elbows and Wyes	-	E 10-UM-50-GPZ E 6-UM-60-GPS
Pan Head Lips	-	E 10-UM-60-GR E 10-UM-65-GRZ
Spud Clamps	E 7-UM-250-KP E 7-UM-200-KP	E 10-UM-60-GR E 10-UM-65-GRZ
Spud Points	E 7-UM-250-KP E 7-UM-200-KP	E 10-UM-60-GR E 10-UM-65-GRZ
Bucket Pins	E 1-UM-250	E 2-UM-55-G
Bucket Eyes and Bottoms. Manganese Steel	E 7-UM-250-KP E 7-UM-200-KP	E 7-UM-250-KP E 7-UM-200-KP
Drive Tumblers	E 1-UM-250 E 1-UM-350-GP	E 1-UM-250 E 1-UM-350-GP
Drive Tumbler Plates. Manganese Steel Carbon Steel	-	E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-60-GRZ
Retard Rings	-	E 10-UM-45-GPZ E 10-UM-60-GR E 10-UM-65-GRZ E 10-UM-50-GPZ E 10-UM-60-GRZ

Cement carriers

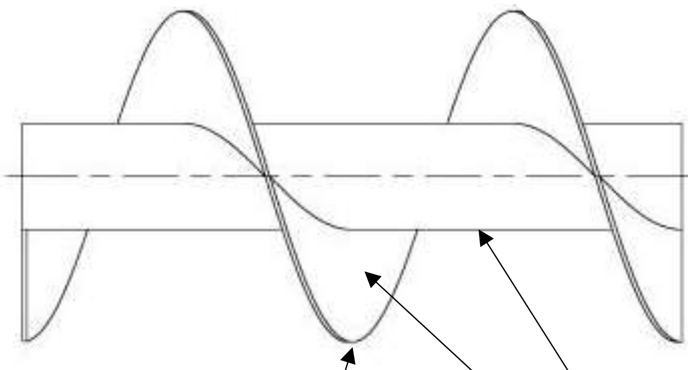
Cement cargos account for about 5% of the world's dry bulk trade. These cargos are typically shipped in bulk, and many bulk carriers are able to transport cement. A cement carrier will be a single-skin or double-skin bulk carrier provided with a cement loading and discharging plant. Traditionally, cement carriers are loaded by gravity or by pressure from silo.

Pneumatic cement carriers.
A more sophisticated way to load or discharge is to deploy a special type of vessel equipped with own compressors and pumps: self-discharging, pneumatic cement carriers. This type uses the principle that when air is pumped through a cement cargo, it acts as if it were liquid. In this way, cement can be loaded easily and, while discharging, can be moved readily to a central trunk at the bottom of holds.

Mechanical cement carriers.
Screw conveyors and conveyor chains are also in use both for mechanical loading and unloading of cement carriers and for the transfer of cargo between ships and shore-based facilities. Screw conveyors are designed to handle fluidisable powdery cargoes such as cement, fly ash and limestone powder under tough conditions. The horizontal screw conveyor distribution arrangement ensures cement is loaded evenly into a ship's holds, both longitudinally and transversely. The vertical screw conveyor is used for elevating the cement above deck level.

Conveyour screws

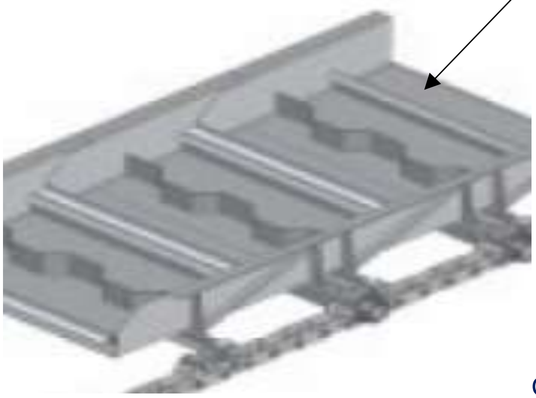
Conveyor screws



Edge surface with:
DIN EN 14700: EZ Fe20
DIN 8555: E 21-UM-65-G
Alternative oxy-acetylene rod consisting of nickel based alloy with tungsten carbides:
DIN EN 14700: T Ni20
DIN 8555: G-21-UM-50 CG

Build up worn areas with:
AWS A 5.4: ~E 307 - 26
EN ISO 3581-A: E 18 8 Mn R 53
DIN: W.Nr. 1.4370
DIN 8556: E 18 8 6 Mn R 26

Hard facing with:
AWS A 5.13: E FeCr-A1
DIN EN 14700: E Fe14
DIN 8555: E10-UM-60-GRZ
Alternative:
AWS A 5.13: E FeCr-E4
DIN EN 14700: E Fe16
DIN 8555: E 10-UM-65-Z



Conveyor chains

MMAW Stick / Electrodes and Self-Shielded (FCAW-S) wire (Open Arc) Hard facing Comparison Chart

The charts are based on resemblance with regards to classification. Please note that the classifications alloy groups can have large variations. This can also be the case for mechanical values (hardness) and suitability. The comparison has not taken into account if the consumable is high or normal recovery type or if it can be used in different positions. It is therefore advisable to contact the manufacturer for finer details and for last updates.

MMAW Electrodes Hard facing Comparison Chart 1

Classification	Build-up (Ferrite/Bainite)		Adhesive (Metal-to-metal)			Metal to Earth Austenitic and Eutectic Carbides
			Martensite	Martensite/ Austenite	Tool steel (Austenite)	
DIN 8555:	E 1-UM-250	E 1-UM-350-GP	E 2-UM-55-G	E 6-UM-60-GPS	E 4-UM-60-SZ	E 10-UM-60-GRZ
DIN EN 14700:	EFe1	EFe1	EFe2	EFe6	EFe4	EFe14
LINCOLN ELECTRIC	**Wearshield BU**	**Wearshield BU30**	**Wearshield MM**	**Wearshield MI**	**Wearshield T&D**	**Wearshield ME**
STOODY (ESAB)	**Build-up** (DIN 8555: E 1-UM-250-P DIN EN 14700: EFe1)	**Build-up LH** (DIN 8555: E 1-UM-250-P DIN EN 14700: EFe1)		**Selfhardening** (DIN 8555: E 6-UM-55-GP DIN EN 14700: EFe8)		**35** (DIN 8555: E 10-UM-55-G DIN EN 14700: EFe14) **2134 CTS** (DIN 8555: E 10-UM-60-G DIN EN 14700: EFe14)
VOESTALPINE BOHLER UTP	**Dur 250** (DIN 8555: E 1-UM-250 DIN EN 14700: EFe1)	**DUR 350** (DIN 8555: E 1-UM-350 DIN EN 14700: EFe1)		**Dur 600** (DIN 8555: E 6-UM-60 DIN EN 14700: EFe8)	**UTP 690** (DIN 8555: E 4-UM-60-ST DIN EN 14700: EFe4)	**Lerduit 61** (DIN 8555: E 10-UM-60-GRZ DIN EN 14700: EZFe14)
ESAB	**OK Weartrode 30HD** Former: OK 83.29 (DIN 8555: E 1-UM-300 DIN EN 14700: EFe1)	**OK Weartrode 30** Former: OK 83.28 (DIN 8555: E 1-UM-350 DIN EN 14700: EZFe1)	**OK Weartrode 50** Former : OK 83.50 (DIN 8555: E 6-UM-55 DIN EN 14700: EZFe2)	**OK Weartrode 55HD** Former: OK 84.58 (DIN 8555: E 6-UM-55-G DIN EN 14700: EZFe6)	**OK Tooltrode 60** Former: OK 85.65 (DIN 8555: E 4-UM-60 DIN EN 14700: EFe4)	**OK Weartrode 60T** Former: OK 84.78 (DIN 8555: E 10-UM-60-GZ DIN EN 14700: EZFe14)
MCKAY (ITW)	**Hardalloy 32**		**Hardalloy 58**	**Hardalloy 58/61/600**	**Hardalloy 61**	**Hardalloy 140**
CERTANIUM	**283FC** **(293,723)**		**281FC, 246FC**	**267**	**221** **(211)**	**246**
All- State welding products (Esab)	**Wear Arc 3 IP**		**Wear Arc 4 IP**	**Wear Arc 5 IP**		**Wear Arc 40**
RANKIN	**BU/700**		**Ranite Bx,B**	**Ranite G,D** **(Ranite31,Ranite A)**		**Ranite 4** **Ranite35** **Ranite j (1)**

MMAW Electrodes Hard facing Comparison Chart 1 (Continue)

Classification	Build-up (Ferrite/Bainite)		Adhesive (Metal-to-metal)			Metal to Earth
			Martensite	Martensite/ Austenite	Tool steel (Austenite)	Austenitic and Eutectic Carbides
DIN 8555:	E 1-UM-250	E 1-UM-350-GP	E 2-UM-55-G	E 6-UM-60-GPS	E 4-UM-60-SZ	E 10-UM-60-GRZ
DIN EN 14700:	EFe1	EFe 1	EFe2	EFe6	EFe4	EFe14
CASTOLIN EUTECTIC (Messer)	**EutecTrode 2B** (DIN 8555: E 1-UM-300P DIN EN 14700: EFe1)			**EutecTrode N 102** (DIN 8555:E 6-UM-55-G)	**EutecTrode 6** (DIN 8555:E 4-UM-60-ST)	**EutecTrode N6006** (DIN 8555:E 10-UM-60-GR)
HOBART (ITW)	Hardalloy 32					
WELDING ALLOYS	**Hardface 250-E** (DIN EN 14700: E Fe1)			**Hardface LE** (DIN EN 14700: T Fe8)	**Hardface AR-E** (DIN EN 14700: E Fe4)	
STULTZ SICKLES	**Special alloy**					**Ultra Hard 60**
WELDMOLD	**Polytrode HD 515**					**Polywear 358**
METRODE (LINCOLN ELECTRIC)		**Met-hard 350** (DIN 8555: E 1-UM-400-GP DIN EN 14700: E Fe1)		**Met-hard 650** **Met-hard 650R** (DIN 8555: E 6-UM-60-GP DIN EN 14700: E Fe2)	**Met-hard 750TS** (DIN EN 14700: E Fe4)	**Met-hard 950** (DIN 8555: E 10-UM-60-GR DIN EN 14700: E Fe9)
SOUDOMETAL		**Tenasoud 105** (DIN 8555: E 1-UM-300)				
SELECTARC	HB 25 DIN 8555: E1-UM-250	**HB 40** DIN 8555: E1-UM-400	**HB 60** DIN 8555: E2-UM-60 EN 14700: E Fe2			

MMAW Electrodes Hard facing Comparison Chart 2

Classification	Severe Abrasions Primary carbides		Severe Impact (Austenite/Manganese)			Abrasion and Impact (Austenite/Carbide)	
DIN 8555:	E 10-UM-60-GR	E 10-UM-65-GRZ	E 7-UM-200-KP		E 7-UM-250-KP	E 10-UM-50-GPZ	E 10-UM-45-GPZ
DIN EN 14700:	EFe15	EFe16	EFe9		EFe9	EFe6	EFe14
LINCOLN ELECTRIC	**Wearshield 60**	**Wearshield 70**	**Wearshield Mangjet**	**Wearshield Frog Mang**	**Wearshield 15CrMn**	**Wearshield ABR**	**Wearshield 44**
STOODY (ESAB)	**XHC** (DIN 8555: E 10-UM-65-G DIN EN 14700: EZFe14)		**Dynamang Nicromang** (DIN 8555: E 7-UM-200-KP DIN EN 14700: EFe9) **Nicromang Pluss** (DIN 8555: E 7-UM-250-KP DIN EN 14700: EFe9)	**Track Wear** (DIN 8555: E 7-UM-250-KP DIN EN 14700: EFe9)	**2110** (DIN 8555: E 7-UM-200-KPR DIN EN 14700: EFe9)	**31** (DIN 8555: E 10-UM-45-GT DIN EN 14700: EFe14)	**19** (DIN 8555: E 10-UM-50-GP DIN EN 14700: EZFe14) **21** (DIN 8555: E 10-UM-55-G DIN EN 14700: EZFe14) **33** (DIN 8555: E 6-UM-40-GT DIN EN 14700: EZFe14) **31** (DIN 8555: E 10-UM-45-GT DIN EN 14700: EFe14)
VOESTALPINE BOHLER UTP		**Lerdurit 65** (DIN 8555: E 10-UM-65-GRZ DIN EN 14700: EFe16)	**UTP 7200** (DIN 8555: E 7-UM-250-KP DIN EN 14700: EZFe9)	**Cronos** (DIN 8555: E 7-UM-200-KP DIN EN 14700: EFe9)	BMC (DIN8555: E7-UM-250-KPR DIN EN 14700: EFe9)	**Dur 650Kb** (DIN 8555: E 6-UM-60 DIN EN 14700: E Fe8)	
ESAB	**OK Weartrode 65T** Former: OK 84.80 (DIN 8555: E 10-UM-60-GZ DIN EN 14700: EZFe16)		**OK 13Mn** Former: OK 86.08 (DIN 8555: E 7-UM-200-K DIN EN 14700: EFe9)	**OK Weartrode 14MnNi** Former: OK 86.28 (DIN EN 14700: EZFe9)	**OK 86.30** (DIN 8555: E7-UM-200-KR/D4 DIN EN 14700: EFe9)	**OK Weartrode 60** Former: OK 83.65 (DIN 8555: E 2-UM-60 DIN EN 14700: EZFe2)	**OK Weartrode 50** Former: OK 83.50 (DIN 8555: E 6-UM-55-G DIN EN 14700: EZFe2)
MCKAY (ITW)	**Hardalloy 55 (155)**	**Hardalloy 55Tic**	**Hardalloy 118**	**Hardalloy 119**	**Chrome-Mang**	**Hardalloy 600**	**Hardalloy 40Tic**
CERTANIUM	**230,250**	**247,297**	**262FC** **(298,299)**	**282**	**106FC, 282FC (245)**	**246**	**215, 222**

MMAW Electrodes Hard facing Comparison Chart 2 (continue)

Classification	Severe Abrasions		Severe Impact (Austenite/Manganese)			Abrasion and Impact (Austenite/Carbide)	
	Primary carbides						
DIN 8555:	E 10-UM-60-GR	E 10-UM-65-GRZ	E 7-UM-200-KP		E 7-UM-250-KP	E 10-UM-50-GPZ	E 10-UM-45-GPZ
DIN EN 14700:	EFe15	EFe16	EFe9		EFe9	EFe6	EFe14
All- State welding products (Esab)	**Wear Arc 40**		**Wear Arc Ni-Manganese**		**Wear Arc Super WH**	**Wear Arc 6 IP**	
RANKIN	**Ranite 4** **Ranite M**		**Ranmang 1**	**Ranmang 3**	**MC** **(Ranmang 3)**	**16** **(Ranite D)** **(Ranitye J)**	**Ranite F**
CASTOLIN EUTECTIC (Messer)	**EutecTrode N6006** (DIN 8555: E 10-UM-60-GR)	**EutecTrode N6710** (DIN 8555: E 10-UM-65-G) **N6715** (DIN 8555: E 10-UM-70-GZ)			**EutecTrode 6450** (DIN 8555: E 7-UM-250-KPR DIN EN 14700: EFe9)		
HOBART (ITW)	**Hardalloy 140**			Hardalloy 118		**Hardalloy 148**	
WELDING ALLOYS	**Hardface HC-E** (DIN EN 14700: E Fe15)	**Hardface CNV-E** (DIN EN 14700: E Fe16)	**Hardface AP-E** (DIN EN 14700: E Fe9)				
STULTZ SICKLES			**Manganese XL**			**Universal HF**	
WELDMOLD			**Polywear 325** AWS: EFeMn-B				
METRODE (LINCOLN ELECTRIC)		**Met-hard 1050** (DIN 8555: E 10-UM-65-GP DIN EN 14700: E Fe16)		**Work-hard 13MN** (DIN 8555: E 7-UM-200-KP (DIN EN 14700: E Fe9)			
SOUDOMETAL					**CoMetMC**		
SELECTARC	**HRT 60** EN 14700: E Fe15				**HB 14Mn** (DIN 8555: E7-UM-250-KP EN 14700: E Fe9 AWS A5.13: ~EFeMn-C)		**HB 63** DIN 8555: (E10-UM-60-GRPZ EN 14700: E Fe14)

Self-Shielded (FCAW-S) wire (Open Arc) Hard Facing Comparison Chart

Classification	Build- up Ferritic Bainitic	Metal to Metal Martensitic		Metal to Metal Tool steel Martensitic
DIN 8555:	MF1-GF-350-GPS	MF1-GF-400-GPS	MF2-GF-55-GP	MF4-GF-60-S
DIN EN 14700:	TFe1	TFe1	TFe2	TFe8
Lincoln	Lincore 33	Lincore 40-O	Lincore 55	Lincore T&D
Stoody (Esab)	Super Build-up 104-O	105-O Rail end 932-O	965-O	102G-O
McKay / Hobart (ITW)	Tube alloy 242-0	Tube alloy 242-O	Tube alloy 258-O/ Armor Wear	Tube alloy 258-O
All- State welding products (Esab)	Wear o Matic 3	Wear O Matic 6	-	-
Certanium Alloys	283FC	-	281FC	
CASTOLIN EUTECTIC (Messer)	Teromatec OA 3010	-	Teromatec OA 4415	-
Rankin Industries	Ranomatic BU	Ranomatic 969-O	Ranomatic BX 2,D	-
Stultz Sickles	-	Stultz Multi Layer 50-S/A	Stultz Multi Layer 50-S/A	-
Welding Alloys	Hardface T-O	Hardface P-O	Hardface W-O	Hardface L-O

Classification	Sever Impact Austenitic Manganese		Abrasion plus Impact Austenitic and Carbides	Sever Abrasion Primary Carbides
DIN 8555:	MF6-GF-45-KP	MF7-GF-250-KP	:MF6-GF-50-GP	MF10-GF-60-CG
DIN EN 14700:	TFe9	TFe9	TFe8	TFe15
Lincoln	**Lincore M**	**Lincore 15CrMn**	**Lincore 50**	**Lincore 60-0**
Stoody (Esab)	**Dynamag-O Nicromang-O Plus-O**	**110-O**	**117-O,121-O,134-O,133-O**	**100HC,101HC-O**
McKay / Hobart (ITW)	**Tube alloy 218-O**	**Tube alloy AP-O**	**Tube alloy 240-O**	**Tube alloy 255-O**
All- State welding products (Esab)	**Wear O Matic Nickel Mang**	**Wear O Matic Super WH**	**Wear O Matic 12**	**Wear O Matic 40**
Certanium Alloys	**-**	**282FC**	**284FC**	**247FC**
CASTOLIN EUTECTIC (Messer)	**TeroMatec 3220**	**TeroMatec 3302**	**TeroMatec 4923**	**TeroMatec 4601**
Rankin Industries	**Ranomang 1**	**Ranomang 3**	**Ranomatic BX-2**	**Ranomatic R-100HD**
Stultz Sickles	**Stulz Manganese XL-S/A**	**Stulz No. 1616S/A**	**Stulz No.12S/A**	
Welding Alloys	**Hardface TIC-O**	**Hardface 19/9/6-O AP-O**	**Hardface NCWB-O**	**Hardface CN-O**

Ships propeller repair

Welding is used for the repair of propellers that may become damaged in service or for reclamation of worn surfaces. However, it is prohibited for certain critical applications relating to Naval Standards. Welding should therefore be done by class approved workshops and according to approved procedures.

Chemical composition of standard cast copper alloys for propellers

Casting grade	Chemical composition %							
	Cu	Al	Mn	Zn	Fe	Ni	Sn	Pb
CU1	52-62	0.5-3.0	0.5-4.0	35-40	0.5-2.5	Max.1.0	0.1-1.5	Max.0.5
CU2	50-57	0.5-2.0	1.0-4.0	33-38	0.5-2.5	3.0-8.0	Max.1.5	Max.0.5
CU3	77-82	7.0-11.0	0.5-4.0	Max.1.0	2.0-6.0	3.0-6.0	Max.0.1	Max.0.03
CU4	70-80	6.5-9.0	8.0-20.0	Max.6.0	2.0-5.0	1.5-3.0	Max.0.1	Max.0.05

Depending on propeller grade:
Preheat temperature can range from 50°C to 150°C (122-302°F).
Interpass temperature can range from 250°C to 300°C (482-572°F).
Stress relieving heat treatment is not necessary if Ni-Al bronze filler metals are used.

Consumables:

Nickel-Aluminum Bronze filler metal is used for MIG and TIG welding of cast and wrought nickel-aluminium bronze parts such as ship propellers, where high resistance to corrosion, erosion and cavitation’s in salt or brackish water is required.

Commonly used Ni-Al bronze filler metals compositions from International welding standards for filler wires and rods:

Zn	Fe	Si	Al	Mn	Ni	Pb	Cu
0.02%	3.00-5.00%	Si 0.10%	8.50-9.50%	0.60-3.50%	4.00-5.50%	0.02%	Rest

Consumable Classification (Wire/rod):

ANSI/AWSA5.7 ERCuNiAl

ASMESFA 5.7 ERCuNiAl

EN 13347: CuAl9Ni4Fe3Mn2

EN14640: CuAl9Ni5

DIN 17331: 2.0923

MMA (Stick electrode) welding is possible. Note AWS A5.13/A5.13M: 2010 Table 3 Copper base surfacing electrode list on next page giving alternative electrode ECuNiAl.

The welding of nickel aluminium bronze alloys is not complicated and can be accomplished by most welders. However, the aluminium rich oxide film which is so important for corrosion resistance can impede welding without the use of correct methodology. It is important that oxides, which can form on the base metal as the part is heated or are present prior to heating, do not form inclusions in the weld bead. Pre-weld and inter-run cleaning are therefore of prime importance.

For more detailed information on welding procedure for propeller repairs contact TE Andersen consulting.

Table 3
Copper Base Surfacing Electrodes—Chemical Composition Requirements

AWS Classification	Annex A Reference	UNS Number[c]	Deposit Composition, weight percent[a,b] Cu	Mn	P	Si	Fe	Al	Zn	Ni[d]	Pb	Sn	Ti	Other Elements, Total
ECuAl-A2[f]	A7.4.1.1	W60617	Rem	g	—	1.5	0.5–5.0	8.5–11.0	g	g	0.02	g	—	0.50
ECuAl-B[f]	A7.4.1.2	W60619	Rem	g	—	1.5	2.5–5.0	11–12	g	g	0.02	g	—	0.50
ECuAl-C	A7.4.1.2	W60625	Rem	—	—	1.0	3.0–5.0	12–13	0.02	—	0.02	—	—	0.50
ECuAl-D	A7.4.1.3	W61625	Rem	—	—	1.0	3.0–5.0	13–14	0.02	—	0.02	—	—	0.50
ECuAl-E	A7.4.1.3	W62625	Rem	—	—	1.0	3.0–5.0	14–15	0.02	—	0.02	—	—	0.50
ECuSi[f]	A7.4.1.4	W60656	Rem	1.5	g	2.4–4.0	0.50	0.01	g	g	0.02	1.5	—	0.50
ECuSn-A[f]	A7.4.1.5	W60518	Rem	g	0.05–0.35	g	0.25	0.01	g	g	0.02	4.0–6.0	—	0.50
ECuSn-C[f]	A7.4.1.5	W60521	Rem	g	0.05–0.35	g	0.25	0.01	g	g	0.02	7.0–9.0	—	0.50
ECuNi[e,f]	A7.4.1.6	W60715	Rem	1.0–2.5	0.02	0.50	0.40–0.75	—	g	29–33	0.02	g	0.50	0.50
ECuNiAl[f]	A7.4.1.7	W60632	Rem	0.5–3.5	—	1.5	3.0–6.0	8.5–9.5	g	4.0–6.0	0.02	g	—	0.50
ECuMnNiAl[f]	A7.4.1.8	W60633	Rem	11–14	—	1.5	2.0–4.0	7.0–8.5	g	1.5–3.0	0.02	g	—	0.50

[a] Single values shown are maximum percentages. Rem = Remainder.
[b] The weld metal shall be analyzed for the specific elements for which values, or a "g," are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for "Other Elements, Total" in the last column of the table.
[c] SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System.*
[d] Includes cobalt.
[e] Sulfur is restricted to 0.015% maximum.
[f] This AWS classification is intended to correspond to the same classification that appears in AWS A5.6, *Specification for Copper and Copper-Alloy Covered Electrodes.* Because of revision dates the composition ranges may not be identical.
[g] These elements must be included in "Other Elements, Total."

There are a number of ships items made from copper alloys that can be in need of resurfacing by welding. Pump and valve housing, impellers and turbine blades. Very often the type of wear will be the same as for propellers: Cavitation wear. Electrodes according to ANSI/AWSA5.7 ERCuNiAl will be the preferred type.

Electrode brands according to ANSI/AWSA5.7 ERCuNiAl

COMPANY	PHILARC	UNIBRAZE	NIHONWELD	WELD MOLD	AMPCO
CONSUMABLE	CuNiAl	Aluminium Bronze A4	N-CuNiAl	4046	Ampco-Trode 46

Alternative hard facing methods and materials

Ceramics
Ceramics can be an alternative help to solve abrasion problems. Ceramic pipes are used in processes where transport of cement, coal, glass particles as well as corrosive and aggressive vapours are exposing equipment to severe abrasive wear.

Ceramic wear plates are used where distribution of large volumes of rough materials causes impact and strain on the equipment. They are often used in barges that load and unload excavated gravel and rocks, and for heavy steel scrap handling.
Alumina: Chemically very stable material with high resistance to wear with a hardness of about 9 on the Mohs scale*. Density 4 g / cm3.
Zirconium oxide: Similar to alumina but has greater resistance to mechanical wear and tear. Density 5.7 g / cm3
Silicon carbide: Has extremely high resistance to mechanical wear and high temperatures. Density 3.2 g / cm3
Tungsten carbide: Very hard and heavy material. Highly resistant to abrasion and acids. Hardness is about 9 on Moh's scale. Density 15.63 g / cm3. High melting point of 2870°C (5198°F).

* Mohs scale of mineral hardness is a scale characterizing scratch resistance of various minerals through the ability of harder material to scratch softer material.

Polymer compounds
Polymer compounds can in some cases, have better wear properties than weld overlays. Specifically concerning cavitation wear in fluid flow environments. Large surfaces that are worn are also much faster overlaid with polymer compounds than with weld bead overlays.
For further information on polymer solutions go to:
www.teandersen.com> Welding Library > Cold welding polymer to the rescue.

Thermal spraying
Thermal spraying is a method of repairing, reconditioning and refinishing surfaces exposed to extensive adhesive wear and abrasion. For further information on thermal spraying go to:
www.teandersen.com> Welding Library > Reclaiming Rotating Parts by Metal Spraying.

Ceramic tails glued into a shaft (75°). Despite this, the recirculated asphalt (bitumen and gravel) have started the wear process.

SUMMING UP:

WHAT TO CONSIDER BEFORE HARDFACING

NAME OF PART____

What is the base material chemical composition?

Carbon steel ☐

Low alloy steel ☐

Manganese steel ☐

Stainless steel ☐

Make simple sketch of part/ location/wear problem

What is the wear problem?

Abrasion ☐

If abrasive wear check out the following:

Type of product causing the wear: ______________________________

Hardness of the particles in the product: ________________________

Size of the particles: _____________________________________

Edge sharpness: ____

Velocity: ____

Angle of introduction towards the substrat___________________________

Ambient temperature _______________________________________

Impact ☐

Adhesive ☐

Cavitation ☐

Heat ☐

Corrosion ☐

Is there a combination of wear problems? _____________________________

Which is the most important? ____

Is there old hard facing layer on the part which needs to be removed? _______________

Is preheat necessary? ____

What about cooling rate? ____

What position is needed for welding? _________________________________

Is build up layer and buttering layer necessary before hard facing? _______________

Any particular welding sequence to be used? ___________________________

What method or process is best to use or available? MMAW ☐ TIG ☐ Wire Welding ☐

What welding consumable to consider for build-up layer and buttering? _______________

____

What welding consumable to consider for hard facing? _________________________