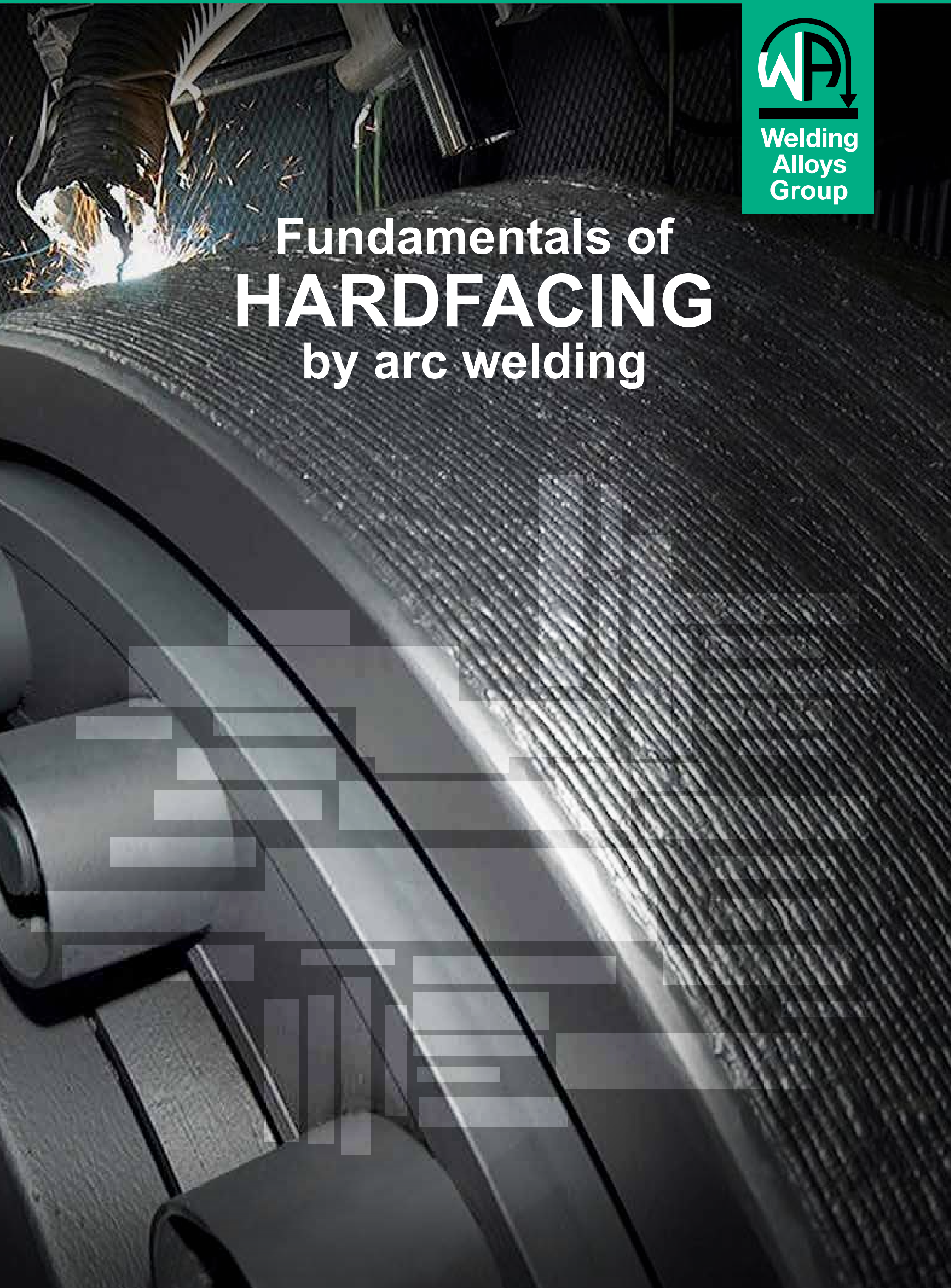
Welding Alloys Group

Fundamentals of HARDFACING by arc welding



Fundamentals of hardfacing by fusion welding

Founded in 1966, the WELDING ALLOYS Group has developed over the years as a manufacturer of cored wires for welding and hardfacing. Its know-how and the technology that it has created have allowed it to become a specialist in hardfacing solutions using semi- or fully automatic continuous arc welding processes.
Regardless of the industry you work in, you are faced with wear. Its effect on your equipment and installations leads inevitably to loss of production and greatly affects the profitability of your business.
With more than 50 years' experience, WELDING ALLOYS' mission is to provide you with solutions to overcome the adverse effects of wear. This document is designed to help you to choose the ideal hardfacing solution.

Our technical 'Spark' solves your industrial challenges

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1 What is wear?

1.1. Definition

Wear is defined as a progressive deterioration through loss of material due to prolonged or overly frequent use. It degrades the condition of a part, leading to a loss of performance.

For the user, this entails:

- reduced lifetime and productivity
- increased risks to personnel
- higher energy consumption & lower yield

Combined, these factors can reault in significant costs. It is therefore essential to factor in the effects of wear on the life of the product: Planning for wear in your maintenance and repair operations is one of the keys to the success of your business.

This document will demonstrate the importance of hardfacing, used as a preventive or as a remedial measure.

1.2. Mechanisms

The study of interacting surfaces in relative motion and its effect on friction and wear is referred to as "Tribology".

To achieve the best possible characterisation of wear mechanisms in metals, three elements have to be understood:

- **The base material**, or substrate, is characterised by its chemical composition and, its production method (rolled, forged, cast), i.e. its mechanical properties. Component geometry also plays a fundamental role. This information allows us to understand its susceptibility to wear and the welding conditions required during repairing, rebuilding, and/or hardfacing.
- **The external element** (abrasive) which causes wear of the substrate is characterised by its dynamic and physical properties. Its hardness, shape, and texture determine the level of damage it will cause, depending on the pressure, speed, and angle of contact with the substrate.
- **The environment** in which the wear occurs is an essential factor in choosing the ideal welding solution. Operational conditions such as temperature, pressure and humidity should be characterised as far as possible.

In the following section, we shall meet the various types of wear. For now it is useful to keep in mind that the main effect of wear is a visible deterioration of the part.

There are three main modes of action: cutting (i.e. forming chips), deformation and gouging/chipping.

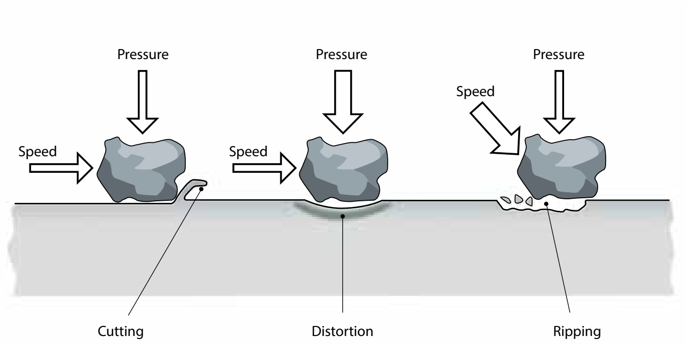
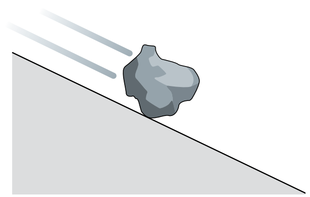


Illustration of the three main modes of wear action

2 Different types of wear

2.1. Low and moderate stress abrasion / low impact



This type of wear is the result of particles rubbing/ sliding on the substrate. As the pressure from these abrasives is very low, they don't change size and don't break up.

Since the angle of attack of these particles is very low, the term "micromachining" is sometimes used.

The following terms are used in the field:

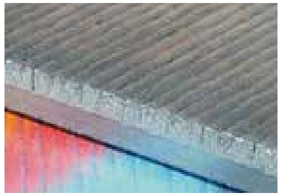
- "Low stress abrasion", where two bodies are involved the abrasive and the substrate.
- "Moderate stress abrasion", where three bodies are involved two surfaces moving against each other with an abrasive between them.

The sharper and harder the abrasive, the higher the abrasion rate. Page 30 shows a table with abrasive hardness for different materials.

As there is no impact effect, substrate ductility is not an issue. As long as the hardness of the base material is higher than that of the external element, wear or abrasion will be very low.

Hardfaced parts, heat treated steel plates & ceramic components are used to resist wear in these situations (e.g., 400 HB).


Heat treated plates

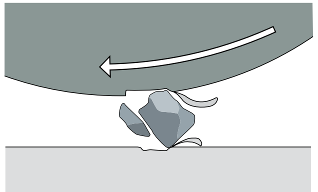

Hardfaced plates


Ceramics

2.2. High stress abrasion / under pressure

Abrasion under high pressure occurs in equipment where the abrasive is compressed between two surfaces. The abrasive is then broken into many pieces.

Due to the high pressure, the wear to the surface manifests itself in the form of chipping, possibly gouging, detachment of hard phases (carbides, borides etc.) or plastic deformation of the matrix.



The surfacing solution should therefore be an optimised balance between yield, ductility and hardness.

Example: coal crusher

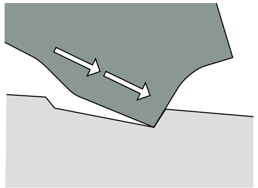
2.3. Severe abrasion (gouging) / high impact

The term “gouging abrasion” is also used. This denotes a combination of low, moderate and high abrasion combined with impact. This type of wear results in large chips and scratches. It may be accompanied by plastic deformation.

A solution to gouging requires the use of ductile materials that resist shocks (force applied to a single point of contact) and impacts (force applied to multi points of contact).

Manganese steels are often used in applications involving repeated shocks, whereas titanium carbide alloys are ideal at resisting impacts.

Example: crusher hammers.



2.4. Adhesion / friction

When two metal bodies rub against each other and material is transferred from one substrate to the other, this is known as “adhesion wear”.

This type of wear occurs under conditions of high temperature, high pressure and friction.

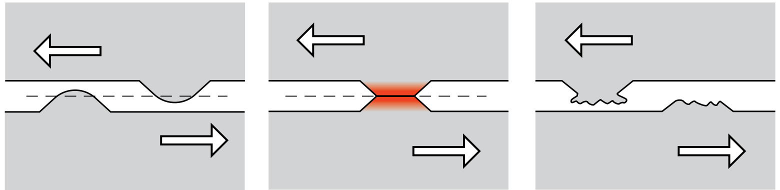
Contact between uneven surfaces, accompanied by relative movement, results in the microfusion of asperities that are immediately sheared off.

Any unevenness may not be visible to the naked eye, as this wear mechanism occurs at the microscopic level.

The rate of adhesive wear depends on several factors: the force acting between the two surfaces, relative speed, temperature of the working environment, surface condition, and surface friction coefficients.

The type of material used also has an influence. The use of materials with identical crystallographic structures tends to increase the risk of adhesion.

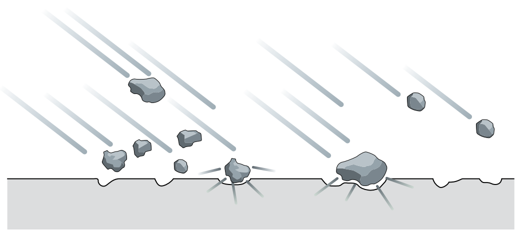
Example: continuous casting rollers; shears; rolling bearings.



2.5. Erosion

Wear by erosion is similar to wear by abrasion. This type of wear occurs when solid particles or drops of liquid strike a surface at high speed.

The rate of wear depends on the angle of attack of the external element and on the speed at which it is projected. The physical properties of the substrate determine the rate of wear by erosion.



At low angles of attack (less than 30°), erosion occurs due to micromachining comparable to low or moderate stress abrasion. The rate of wear depends directly on the substrate's hardness.

At a higher angle of attack (30 to 90°), the erosive particles will deform or even chip the substrate. It then becomes necessary to use materials that are capable of absorbing the energy released by the impact without deforming or cracking.

Example: sludging equipment

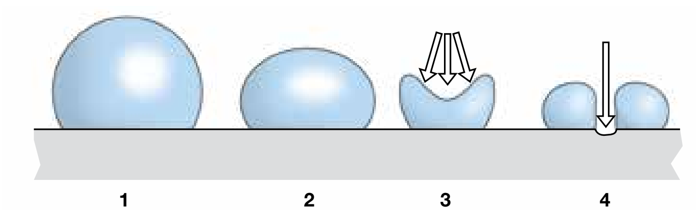
2.6. Cavitation

Cavitation occurs in highly turbulent liquids in contact with a solid surface. Cavities are formed in the liquid and implode, creating wear. The term "cavitation erosion" is also used.

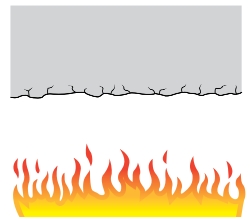
Repeated cavitation results in cyclic loads, wear and base metal fatigue. Fatigue cracks then result in component failure.

Under such stresses, materials offering high toughness show greater resistance to this type of wear as they dissipate the energy released by the implosion of the cavities.

Example: hydroelectric turbine blades.



2.7. Thermal fatigue



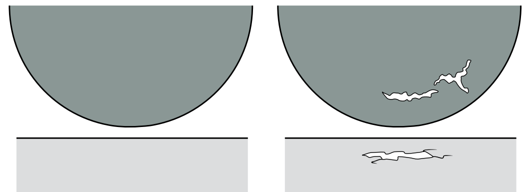
This type of fatigue refers to wear generated by thermal cycle loads on the base metal. When a part is repeatedly heated and cooled, expansion and contraction occur. These processes lead to surface cracking known as "thermal fatigue cracking".

Example: Forge tools, hot rolling rollers.

2.8. Fretting

The types of wear mentioned previously result in a continuous loss of material. "Fretting" is caused when there is a recurrent rolling or sliding action between two components. Under such conditions, a sudden loss of material, in the form of pitting or chipping, will be observed. Parts rolling or sliding under high pressure are subjected to heavy mechanical loads. Cracks may appear and propagate under load, and may even cause spalling or gouging.

Example: gear teeth, rails, roller presses.



2.9. Corrosion

Wear by corrosion is a vast and complex topic. To meet this challenge, cladding solutions are often used. Austenitic stainless steels (300 series) and nickel base alloys are preferred.

In welding qualification tests, this type of surfacing must meet certain requirements, particularly crack-free 180° bending. Hardfacing does not require this type of test.

For hardfacing applications, corossion is not a major issue.

Example: Paper screw conveyor (hardfaced with Tungsten carbide in a Nickel base matrix); or Continuous casting rolls (martensitic stainless steel weld overlay)

2.10. Combined wear

In some applications, the equipment may be subjected to several types of stress at once. This results in a combination of different types of wear.

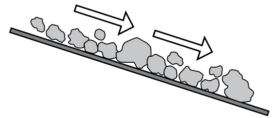
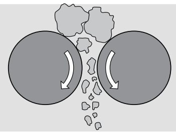
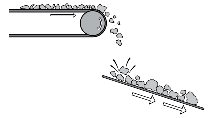
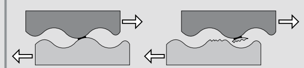
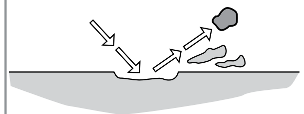
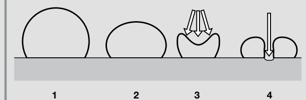
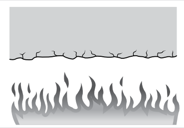
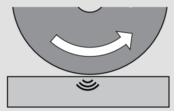
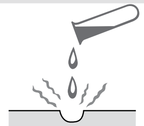
Corrosion and/or high temperature may combine with other types of wear: these are known as secondary factors.

The selection diagrams on pages 46 and 47 will guide you towards the most suitable solution for your needs.

Continuous casting rollers

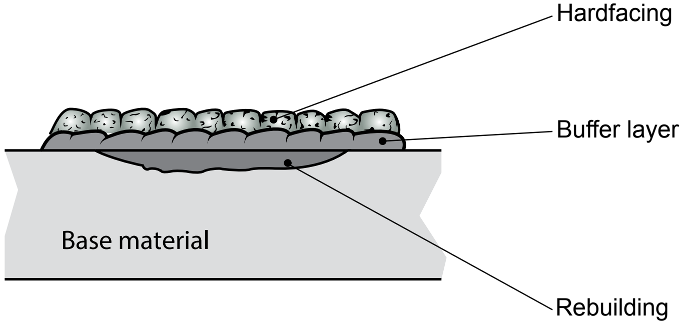
Forging closed dies

2.11. Summary table

Type	Diagram	Damage observed	Frequency
Moderate stress abrasion/low impact		Cutting Micromachining Scratches	
High stress abrasion/ under pressure		Deformation Gouged chips	60 %
Severe stress abrasion (gouging)/ high impact		Scratches Large chips gouged out Deformation	
Adhesion/Friction		Transfer of material	15%
Erosion		Micromachining Change of surface texture	7%
Cavitation		Loss of material	3%
Thermal fatigue		Thermal fatigue cracking	10%
Fretting		Pitting - Chipping Deformation - Impressions	
Corrosion		Fouling, loss of material, etc.	5%

3 Hardfacing terminology

Some of the most important terms used in maintenance, repair and hardfacing are described here. Each of them requires special welding preparation.



3.1. Rebuilding

"Rebuilding" is the restoration of a part to its initial dimensions when its geometry has been changed by wear. Normally, a homogeneous filler metal is used: its chemical composition and mechanical characteristics are similar or identical to those of the base metal.

In some cases, however a heterogeneous alloy could be used, provided its characteristics are compatible with those of the substrate.

The three major factors in choosing a suitable filler metal for rebuilding are:

- The risk of cold cracking: both the preheating temperature and the interpass temperature need to be defined (typically determined by base material type).
- The service temperature and, therefore, the differences in thermal expansion between the filler metal and the base metal.
- Compatibility between the rebuilding filler metal and any subsequent surfacing.

3.2. Buffer layer

Also known as the "sub-layer" or "metallic transition", a "buffer layer" is used when necessary to overcome problems of incompatibility between substrate and cladding.

Why use a buffer layer?

- To provide a good base between the base metal and the hardfacing.
- To avoid the propagation of shrinkage cracks from the hardfacing to the base metal.

Great care must be taken when choosing the filler metal for the buffer layer. If differences in elasticity or thermal expansion between the base metal, buffer and cladding are too great; excessive stresses may be generated at the weld joints. This may cause it to fail prematurely.

3.3. Hardfacing

"Hardfacing" is the deposition of a surface layer by welding, which is harder than the base material. Its purpose is to give wear resistance. Hardfaced layers may also be characterised by the following properties:

- Soundness (cracks are acceptable in some cases).
- Toughness, depending on the need to resist impacts.
- Resistance to environmental stresses such as corrosion and high temperatures.

Hardfacing may involve depositing one or several layers of weld metal. Some types are designed to be appplied in one layer only, while others can be applied without limit.

"Preventive hardfacing" is the application of hardfacing techniques to the production of a brand new component. In this case, the nature of the base metal may be less relevant, apart from cost considerations. "Remedial hardfacing" involves reconstitution of an already worn part, so compatibility with the material of the part needs to be considered.

4 Hardfacing by arc welding

4.1. Benefits of hardfacing

By hardfacing your equipment, you will obtain the following benefits:

- Reduced maintenance
- Reduced operation costs
- Lower repair costs
- Extended equipment lifetime

4.2. Hardfacing arc welding processes

▶▶▶ Gas Tungsten Arc Welding process

In the TIG process, an electric arc is produced between a refractory tungsten electrode and the part. A metallic filler wire may or may not be used.

The weld pool is protected from oxidation by an inert atmosphere (often argon).

▶▶▶ Shielded Metal Arc Welding process

The consumable electrode is composed of a solid core wire and a flux covering. An electric arc creates a weld pool between the electrode core and the part. The slag produced by the fusion of the coating protects the molten metal against oxidation, and can contribute to the deposit's chemical analysis.

▶▶▶ Tubular electrode

A tubular electrode consists of a thin steel tube filled with a powder mixture. This type of electrode is only used for hardfacing applications. A uniform electric arc is formed between the tube wall and the part. This results in lower dilution and wider deposits compared with a conventional coated electrode.

This type of electrode is less susceptible to moisture pickup than standard electrodes

▶▶▶ Gas Shielded Metal Arc Welding process

The molten metal is obtained by creating an electric arc between a wire electrode (solid or tubular cored) and the base metal. Flux cored wires:

- Improve fusion characteristics,
- Protect the molten metal against excessive oxidation.
- Offer a wider range of alloys that can be deposited.

Depending on the protective gas used, the terms Metal Inert Gas (MIG) and Metal Active Gas (MAG) are often used.

This procedure is easy to automate.

▶▶▶ Self shielded process / open arc process

Process identical to MIG/MAG. It has the advantage of not requiring the use of a protective gas.

It is usually used in the following cases:

- Working conditions unsuitable for other welding procedures (outdoor welding, draughts etc.).
- Exposure to the atmosphere has no negative effect on deposit performance.

Also known as "Open arc", this procedure is particularly used for hardfacing solutions (excellent hardness and wear-resistance characteristics).

▶▶▶ Submerged arc welding process

The molten metal is generated by an electric arc between a wire and the part, beneath a "blanket" of powdered flux. The electric arc is not visible and the welding flames are mostly absorbed by the flux layer.

The procedure's configuration and the use of powder flux restricts its application to flat welding positions on plates and rolls.

The submerged arc welding procedure provides very high deposit rates.

Note: This document does not cover all welding procedures (thermal spraying, laser etc.).

Full name	Abbreviation	Designation EN ISO 4063	Type	Precautions	Weld pool protection	Dilution	Typical deposit rate
Gas tungsten arc welding	TIG GTAW	141/143	Manual/Automatic	Electric arc	Gas	5 - 15%	0.5 - 1.5 kg/h 1.1 - 3.3 lb/h
Shielded metal arc welding	MMA SMAW	111	Manual	Electric arc Baking	Slag	15 - 30%	1.0 - 3.0 kg/h 2.2 - 6.6 lb/h
Arc welding with tubular electrode	TE	/	Manual	Electric arc	-	8 - 30%	2.0 - 4.0 kg/h 4.4 - 8.8 lb/h
Gas shielded metal arc welding with cored wire	MAG FCAW	136/138	Semi-automatic/Automatic	Electric arc	Gas	15 - 35%	3.0 - 10.0 kg/h 6.6 - 22 lb/h
Arc welding with self-protecting cored wire (no protective gas)	FCAW	114	Semi-automatic/Automatic	Electric arc	With or without slag	15 - 35%	3.0 - 12.0 kg/h 6.6 - 26.4 lb/hr
Submerged arc welding	SAW	12-	Automatic	Flux baking	Slag	30 - 50%	5.0 - 20.0 kg/h 11.0 - 44 lb/h


Gas tungsten arc welding


Shielded metal arc welding


Arc welding with tubular electrodes


Gas shielded metal arc welding


Unshielded metal arc welding

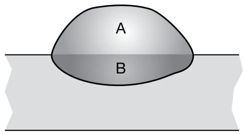

Submerged arc welding

4.3. Dilution

Control of dilution is essential when surfacing. Dilution affects the chemical composition of the deposit, hardness and quality.

During welding, some of the base metal dissolves into the weld pool, diluting it.

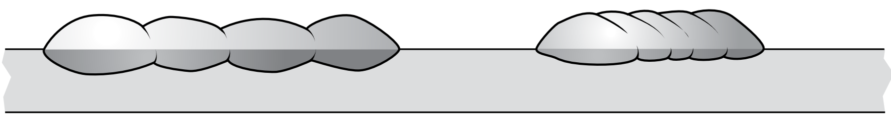
Dilution is calculated as follows: $\% \text{ dilution} = \frac{B}{A + B} \times 100$



During surfacing operations, dilution should be limited to optimise deposit characteristics, whilst ensuring a good fusion with the substrate.

How can dilution be controlled?

- Select the right welding procedure, particularly heat input.
- Welding sequence:
  An overlap between weld passes, of about 50%, provides good dilution control. Multi-pass surfacing results in lower dilution than single-pass surfacing.



- Choose the correct polarity: DC+; DC-; AC
  Changing the polarity can influence the dilution rate.
- Welding technique
  The heat input is directly related to the welding technique: straight or weave bead technique.
- Welding position:
  The horizontal-vertical position (PC) should be used if possible as it produces less dilution than flat welding (PA).

For hardfacing applications, several factors influence the choice of welding procedure:

- Productivity and deposit rate.
- Surfacing thickness.
- Working environment: workshop or outdoors.
- Option of automation.
- Repetitiveness of the work.
- Bonding quality.

"Bonding quality", is directly related to the penetration of the bead in the substrate. Where there are impact stresses, a surfacing with high bonding strength will perform better over time.

Bonding quality is important in resisting impact stresses. A poorly bonded coating will tend to spall off under impact. This can be mitigated by avoiding too sharp a change in composition at the fusion line, thus avoiding a large change in mechanical properties. One way of ensuring this is to adjust the welding conditions to give high penetration and thus high dilution in the first layer. Subsequent layers will reach the target composition.

In extreme cases, a first layer of intermediate composition may be needed.

4.4. Bead patterns

In some cases, geometric weld beads provide better wear resistance than a smooth hardfaced surface.
This type of deposit is an economical solution to wear caused by low or moderate abrasion, under low impact.

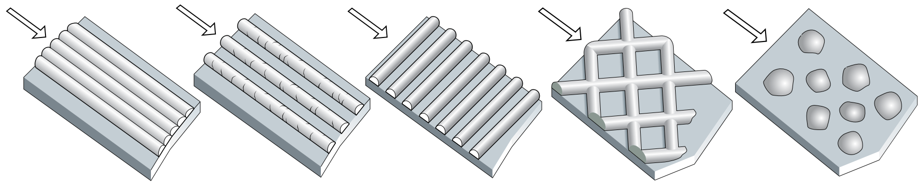
For these applications, the type of geometry to use depends directly on the size and properties of the abrasive.

Roller press with chevrons for crushing.

The principle of this type of surfacing consists of restricting relative movement of the abrasive materials on the parts and creating an anti-wear barrier by capturing the material in the hollow areas.

There are various types of pattern:

- Juxtaposed passes with continuous overlap.
- Passes deposited at regular intervals.
- Cross/grid passes.
- Spot welds.



Juxtaposed passes *Regular intervals passes* *Grid passes* *Spot welds*

▶▶▶ Juxtaposed passes with continuous overlap

To counter severe abrasion, the hardfacing is continuous across the whole of the surface concerned. This ensures that there is no contact between the external element and the base metal.

The beads are juxtaposed with a 50% interpass overlap to guarantee optimal surfacing characteristics (by restricting dilution). In most cases, the weld beads are oriented in the same direction as the flow, thus allowing continuous passage of material.

▶▶▶ Passes deposited at regular intervals

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 is reduced.

Bead direction relative to the operating flow:

- Larger abrasives: the beads are deposited parallel to the flow.
- Medium or fine abrasives, sand or soil: the weld beads are oriented at right angles to the flow with a crack-free deposit. Spacing of the beads will depend on the nature of the abrasive and whether it is wet or dry.

In a wet environment, an agglomeration of particles forms that lodges more readily between the beads. In this case, the space between the beads may be increased. However, to guarantee proper protection, it is advisable to limit this distance.

▶▶▶ Grid passes

Cross beads can be used to create a grid pattern. The beads are oriented at angles of between 30° and 90°.

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).

The smaller the non-surfaced area, the greater the protection given to the abrasion surfaces by the fine particles.

▶▶▶ Spot welds

For low or moderate abrasion, this hardfacing 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.

Wear plate made with grid passes

Bucket teeth made with spot welds and grid passes

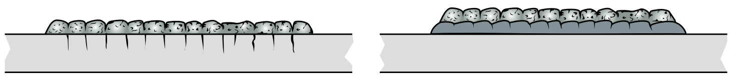
FCB Horomill® with chevrons

Bucket with grid passes

4.5. Shrinkage cracks

Weld deposits containing hard phases (carbides, borides etc.) are especially sensitive to shrinkage on cooling which generates cracks. These are the result of the natural relaxation of stresses in the deposit. They avoid the risk of severe spalling in use, without adversely affecting the deposit's resistance to wear.

These shrinkage cracks run across the welding bead and are regularly spaced. Where shock/impact loads occur, it is important to ensure that these cracks do not spread to the base metal. Therefore, it is necessary to apply a special buffer layer as a barrier to cracking.



"Shrinkage cracks" should be differentiated from "embrittlement cracks". The latter appear in the form of crazing and may lead to material spalling off, with a consequent loss of protection. Similarly, longitudinal cracks are a bad sign. They are often evidence of contamination in the weld.

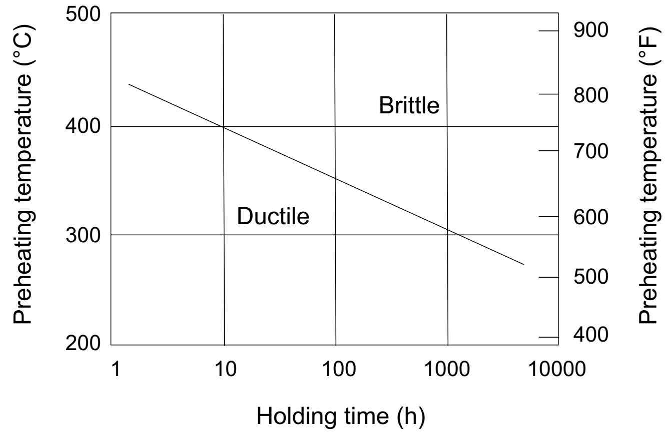
If need be, the cracking of some filler metals can be eliminated. To do so, the part must be preheated adequately and the correct cooling rates must be observed.

This is the case with cobalt base alloys (e.g. STELLOY 6). As they are required to guarantee good anti-corrosion protection, cracks cannot be tolerated.

4.6. Preheating temperature

The need for preheating before welding depends on the type of base metal used. Industries that require hardfacing mainly use non-alloy, low alloy, high alloy and manganese steels, as base materials.

Where an austenitic 11-14% manganese steel is used, preheating must be avoided, as temperatures above 150°C during welding entail a major risk of embrittlement. The following graph illustrates the fragile behaviour of these materials as a function of their exposure to high temperature:



Behaviour of 14%Mn steels when exposed to heat.

For the other steels, preheating before welding can have several benefits:

- It softens the structure of the heat-affected zone by slowing the cooling rate.
- Slower cooling spreads the post-welding stresses.
- Slower cooling improves hydrogen degassing.
- Preheating increases penetration of the base metal and thus improves the bond between it and the weld metal.

To determine the correct preheating temperature, it is essential to know the chemical composition of the base metal, plus the geometry of the part to be welded.
The latter factor influences the distribution of heat. In the case of a very thick substrate, even if it has a low carbon equivalent, light preheating may be required to limit the cooling rate and the risk of "hardening".

Carbon and certain alloying elements, determine the preheating temperature.

Their combined effect is given by the "carbon equivalent" (Ceq) as follows:

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

The table below gives approximate preheating temperatures required for the various base metals

Carbon equivalent	Weldability	Preheating	Postheating
Ceq < 0.35	Good	Light preheating	Not required
0.35 < Ceq < 0.6	Acceptable	150 – 250°C	Preferable
Ceq > 0.6	Precautions are required	> 250°C	Required

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

In certain cases, even if the C-Mn base metal has a Ceq<0.35, the use of a cobalt base hardfacing (STELLOY 6) requires a minimum preheat of 300-350°C. In addition, to avoid cracking in the deposited metal, slow cooling is required (typically less than 50 °C per hour).

Flange borehole cladded with STELLOY 6-G.

Automatic weld overlay using TIG hot wire process (STELLOY 6 TIG)

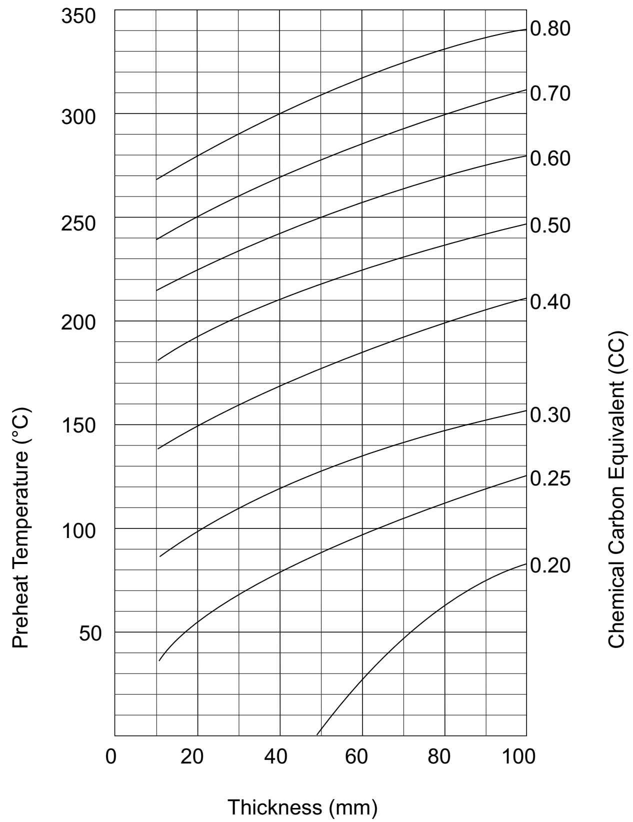
Several methods can be used to calculate the theoretical preheating temperature. We shall use the following Seferian formula:

Preheating T° = 350 $\sqrt{(C) - 0.25}$

(C) represents total carbon equivalent. It is the sum of chemical carbon equivalent (CC) and carbon equivalent and thickness (CET).
0.25 is the upper limit for carbon for weldable carbon steels.

$$CC = C + \frac{Mn + Cr}{9} + \frac{Ni}{18} + \frac{7\ Mo}{90}$$

(CE) = 0.005 x (Substrate thickness in mm) x (CC)
(C) = (CC) + (CET)



Seferian diagram.

5 Characterisation tests for your hardfacing

5.1. Characterising the base metal: sparking and magnetism

Before planning a repair-maintenance operation, it is important to identify the base metal. To do so, two items of information are essential: its chemical composition and its production history.
If the composition is not known, the PMI (Positive Material Identification) method or spectrometry may be used.

The magnetism test, and the spark test, are simple methods that are used to identify metals.

Non magnetic	Slightly magnetic	Highly magnetic
300 series austenitic stainless steels Manganese stainless steels Copper Brass Bronze Aluminium	Monel (Nickel - Copper) Work-hardenable stainless steels Duplex stainless steels	Ferritic stainless steels Carbon steels, low and high alloy steels (typically up to 17% Cr without Mn or Ni) Cast irons Nickel base and cobalt base alloys

Magnetic behaviour of metals and alloys

The sparking behaviour of a material may be observed by applying a grinding wheel to its surface:

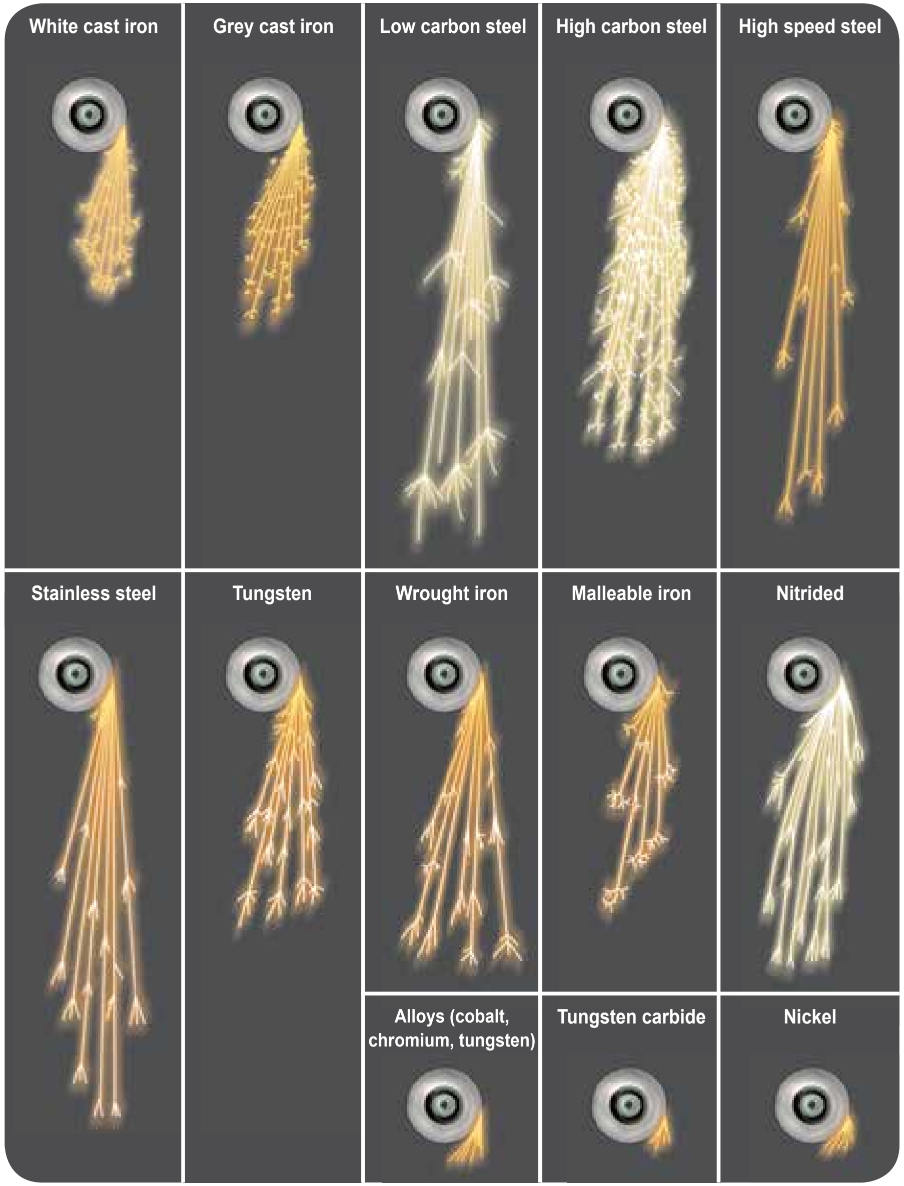


Illustration of the sparking behaviour of various materials.

5.2. Hardness tests

The mineralogist Friedrich Mohs introduced the concept of “hardness” at the start of the 19th century. He established a scale that he used to classify minerals according to their scratch-resistance.

Since the invention of Moh’s scale, more quantitative methods of determining hardness have been developed. They generally depend on measuring the penetration of material by a hard body, under the action of a calibrated force

"Penetration hardness tests" are widely used in hardfacing operations to characterise the materials involved (base metal, external element or deposited metal).

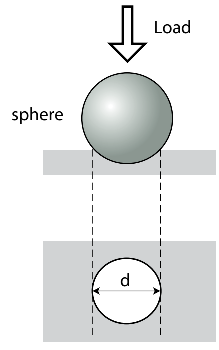
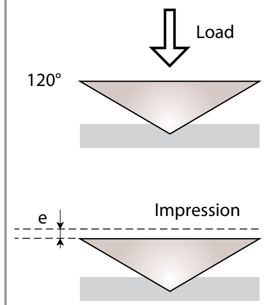
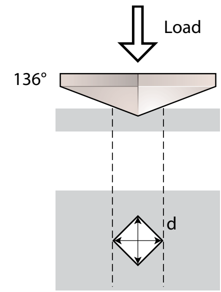
As they are usually quick and easy to carry out, hardness tests are used both in the workshop and on-site. It is useful to note that there are many portable measuring devices that use various techniques (rebound, micro indentation, Ultrasonic Contact Impedance etc.). The interpretation of these hardness values, however, requires an experienced eye and a knowledge of their limitations.

Also, it is important not to confuse "hardness" with “toughness” and “resistance to abrasion”.

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.

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

Using these measurement tools, it is possible to characterise external elements, surfacing (matrix and hard phase) and substrates.

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

Type	Symbol	Hardness (HV)
Carbides	SiC	3000
	TiC	3200
	VC	2900
	NbC	2000
	Cr_2C_3	1350
	Mo2C	1500
	WC/W_2C	2000/1800
Borides	TiB_2	3300
	VB_2	2100
	NbB_2	2600
	CrB_2	2100
	MoB	2500
Nitrides	Si_3N_4	3300
	TiN	2100
	VN	1500
	NbN	1400
	CrN	1100

Examples of Vickers hardness values for common materials.

5.3. Abrasion tests

Low to moderate stress abrasion is one of the main causes of wear. Hard surface coatings are a popular solution for combating this type of wear and a test exists to compare them.

The ASTM G65 test is a “Destructive test to compare the resistance of different surfacings to wear by low or moderate stress abrasion”.

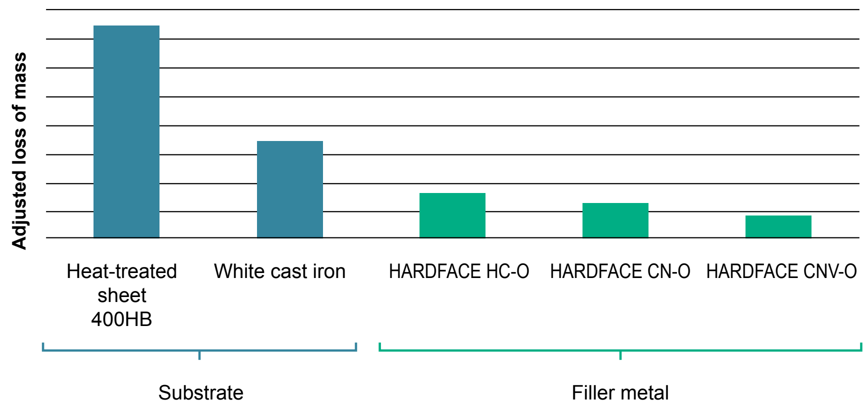
Simply described, the test consists of placing a test piece under constant force against a rotating wheel. An abrasive (e.g. graded silica sand) is introduced between

them at a measured rate. This test simulates in half an hour wear that would occur over thousands of hours of service. The principal is illustrated below.

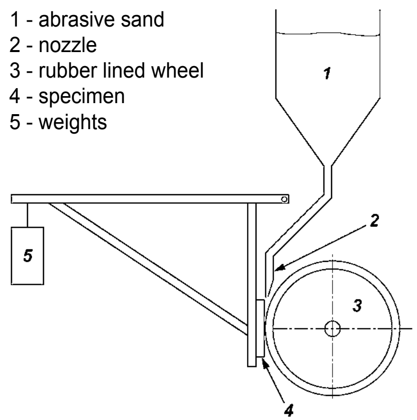
At the end of the test, the volume lost by the sample is measured. By this means, different types of hardfacing may be compared and the best one selected for the application.

WELDING ALLOYS performs these tests in-house and has created a large database that allows an efficient choice at an economic price.

ASTM G65 abrasion test



Adjusted weight loss for three chromium cast iron wires.



ASTM G65 Test (schematic)

Specimen’s appearance after testing

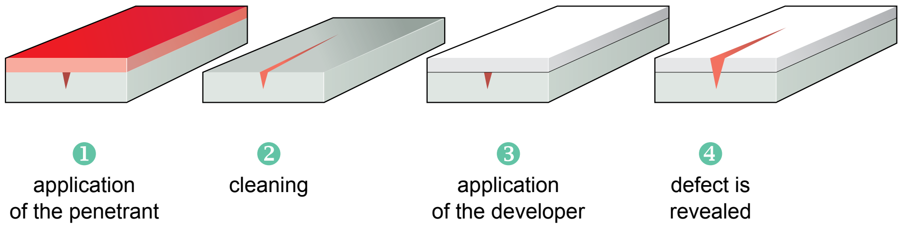
5.4. Dye penetrant testing

Cracking can occur in both the base metal and the deposited metal. There are various causes but, usually, it is directly related to the welding conditions.

Although cracks are sometimes tolerated, a deposit free from cracks and surface-breaking indications that may be invisible to the naked eye is often required.

PT, or Dye Penetrant Testing, is a surface inspection technique used to reveal surface-breaking defects on all types of non-porous materials. The inspection comprises of three main stages:

- Apply a liquid penetrant to the test part. Leave for 15-30 minutes while the liquid infiltrates the surface-breaking defects.
- Remove any excess penetrant with a dry, white, lint-free cloth
- Apply a thin layer of developer to "bleed out" the liquid remaining in the defects by capillary action. This produces a coloured indication that characterises the defect.



Stages of dye penetrant testing.

6 Choosing the right hardfacing consumable

6.1. Standard classifications according to EN 14700

Welding consumables for hardfacing are required to resist various types of wear and are classified according to standard EN 14700 designations.

These classifications specify the chemical composition of the weld deposit excluding dilution by the base metal. There are two parts to the classification:

- The product form "T", for cored tubular products.
- The alloy symbol for the chemical composition excluding dilution.

Example:

A 27%Cr and 5%C chromium cast iron cored wire (HARDFACE HC-O) would have the designation T Fe15.

	C	Cr	Ni	Mn	Mo	W	V	Nb	Others	Base
Fe15	4.5 - 5.5	20 - 40	≤ 4	0.5 - 3	≤ 2	-	-	≤ 10	B	Fe

A Cobalt base grade 6 cored wire (STELLOY 6-G) would have the designation T Co2.

	C	Cr	Ni	Mn	Mo	W	V	Nb	Others	Base
Co2	0.6 - 3	20 - 35	≤ 4	0.1 - 2	-	4 - 10	-	-	Fe	Co

The chemical composition of the filler metal allows knowledgeable users to understand the product's functionality quickly. Each element or combination of elements in an alloy has a particular function; it could 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 table on the following pages describes the main influence of alloy elements in the deposit.

6.2. Description of the elements

	Description	Hardnesses & Carbides	Performance at temperature	Resistance to shocks	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 workhardening. 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.	▲▲	▲▲▲▲	▲▲	▲▲	▲▲▲▲

6.3. Classification by product family

Since the 1940s, the literature related to the topic of "Hardfacing" has increased considerably. To make the topic more readily understandable, the authors have divided filler metals into four product families. [1] [2]

- Group 1: Iron base with less than 20% alloying elements.
- Group 2: Iron base with more than 20% alloying elements.
- Group 3: Non-ferrous alloy, cobalt or nickel base.
- Group 4: Tungsten carbide.

▶▶▶ Group I : Iron base with less than 20% alloying

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.

Designation	C	Mn	Si	Cr	Mo	Ni
HARDFACE BUF	0.12	1.2	0.5	1.5	+	
SPEEDARC X121T5-K4	0.07	1.4	0.5	0.55	0.4	2

Example of "low-alloy" filler metals

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,
- Elements that refine the structure, such as manganese.

Weld deposit hardness may vary from 250 to 700HV.

[1] Weld surfacing and hardfacing: The Welding Institute
[2] Hardfacing by welding: M. RIDDIHOUGH

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 and agricultural activities.

Designation	C	Mn	Si	Cr	Mo	Hardness 3 layers	Structure
ROBODUR K 250	**0.1**	1.5	0.7	**1.5**	**0.2**	250 HB	Bainite
ROBODUR K 350	**0.15**	1.5	0.7	**2**	**0.2**	350 HB	Bainite/Martensite
ROBODUR K 450	**0.4**	1.5	0.7	**2.5**	**0.5**	450 HB	Martensite
ROBODUR K 600	**0.5**	1.2	0.7	**6**	**0.7**	600 HB	Martensite
ROBODUR K CERAMIC	**0.35**	0.7	**2.5**	**9.5**		57 HRC	Martensite
HARDFACE T	**0.15**	1.5	**0.9**	**1.5**		32-33 HRC	Bainite / Martensite
HARDFACE L	**0.5**	1.6	**2.3**	**8.5**		57 HRC	Martensite

Example of "medium alloy" filler metals

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. Martensitic stainless steels are widely used in steelmaking and forging for casting, rolling and forming operations.

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 buffer layer over-alloyed in chromium (~ 17%) to guarantee metallurgical soundness and to avoid cracking in service.

Designation	C	Mn	Si	Cr	Ni	Mo	N	V	W	Co	Hardness 3 layers
CHROMECORE 430	**0.05**	1	0.8	**17.5**							220 HB
CHROMECORE 414	**0.05**	1.2	1	**13.5**	**4**	0.5					40 HRC
CHROMECORE 434N	**0.05**	1.2	0.7	**17**	**3.5**	0.5	0.08				38 HRC
CHROMECORE 414N	**0.05**	1.2	0.8	**14**	**3.5**	1	0.07				42 HRC
CHROMECORE 434DN	**0.05**	1.2	0.8	**16.5**	**3**	0.5	0.08	0.5	**0.8**	**2**	40 HRC
CHROMECORE 414DN	**0.05**	1.2	0.8	**13.5**	**4**	0.5	0.07	0.5	**0.8**	**2**	42 HRC

Example of "high alloy" filler metals

Tool steels

Tool steels are used for high temperature forming in repeated cycles. They must be able to withstand a temperature range of 500-600°C without softening. Elements such as molybdenum, vanadium, titanium, and tungsten are added to ensure this.

Designation	C	Mn	Si	Cr	Mo	Ti	W	Others	Hardness 3 layers
ROBOTOOL 46	0.2	1	0.6	5	4	0.3			42-45 HRC
ROBOTOOL 47	0.2	1	0.6	6	4	0.3			40-42 HRC
ROBOTOOL 58	0.37	1.4	0.6	7	2.5	0.3			54-58 HRC
HARDFACE WLC	0.25	2	0.8	6.5	1.5		1.5		43-45 HRC
HARDFACE W	0.5	2	0.8	6.5	1.5	0.2	1.5		54-56 HRC
HARDFACE WMoLC	0.3	0.8	0.6	6.5	2		2	V: 0.6	50-53 HRC
HARDFACE AR	1.1	0.4	0.25	5	7.6		2.2	V: 1.1	60-63 HRC

Example of "tool steel" filler metals

Forging tools - knives, closed dies, hammers and mandrels - are made from these steels, or surfaced with them.

They exhibit admirable resistance to the combined effects of thermal fatigue, plastic deformation and fretting.

In the following sections, we shall see that other, more highly alloyed solutions are available, based on cobalt and nickel alloys (STELLOY).

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.

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 to give a purely austenitic structure.

Unfortunately, solution annealing is not always possible. Excessive interpass temperatures and overly slow cooling must be avoided. Cored wires are ideally suited to achieve this, combining metallurgical soundness with productivity.

When surfacing with 14 % Mn steel on a non or low alloy substrate, the use of an austenitic stainless buffer layer (307 or 312) 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.

Designation	C	Mn	Si	Hardness 3 layers As welded	Hardness 3 layers Workhardened
HARDFACE NM14	**1**	14	0.5	200 HB	46 HRC

Example of an "austenitic manganese" filler metals

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. This type of alloy is often used in a buffer layer before depositing a 14% Mn alloy.

It should also be noted that the presence of chromium means flame-cutting cannot be used on this alloy.

Designation	C	Mn	Si	Cr	Ni	Hardness 3 layers As welded	Hardness 3 layers Workhardened
HARDFACE 19 9 6	**0.1**	**6**	0.5	**19**	**9**	180 HB	47 HRC
HARDFACE AP	**0.4**	**16**	0.5	**14**		240 HB	48 HRC

Example of "chromium-manganese steel" filler metals

Tool steels

Thanks to alloying with cobalt, chromium and molybdenum, HARDFACE DCO filler metal is a superalloy offering performance very similar to cobalt base alloys. It is the perfect answer to high temperature stresses (500-600°C).

Designation	C	Mn	Si	Cr	Mo	Ni	Co	Hardness 3 layers
HARDFACE DCO	**0.15**	0.4	0.7	**14**	**2.5**	0.5	12.5	47 HRC

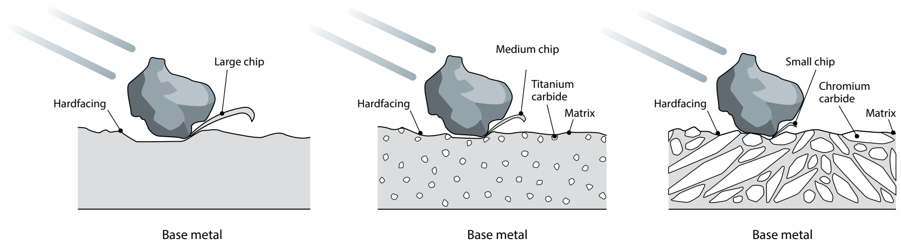
Example of "tool steel" filler metals

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 the perfect answer. The fine regular distribution of hard phases provides excellent resistance to combined stresses.



Influence from different structures in resisting abrasion.
From left to right: ROBODUR K 650, HARDFACE TIC; HARDFACE HC (similar hardness).

Designation	C	Mn	Si	Cr	Mo	Nb	Others	Hardness 3 layers	Matrix structure
HARDFACE HC	**5**	1.5	1.5	**27**				58 - 64 HRC	Austenitic
HARDFACE CN	**5**	0.5	1	**22**		**7**		62 - 64 HRC	Austenitic
HARDFACE CNV	**5.5**	0.5	1.5	**22**	**5.5**	**6**	**W: 2 V: 1**	65 HRC	Austenitic martensitic
HARDFACE DIAMOND	**>5**	1	1	**>10**		**+**	**V: +**	60 - 65 HRC	Austenitic martensitic
HARDFACE HC333	**3.5**	0.2	1	**32.5**	**0.5**			60 HRC	Austenitic
HARDFACE TIC	**1.8**	1.2	0.7	**6.5**	**0.8**		**Ti: 5 V: 0.2**	56 - 60 HRC	Martensitic
HARDFACE BN	**0.5**	2	1.3				**B: 4.5 Ni: 2**	65 HRC	Martensitic
HARDFACE BNC	**2.5**	2	0.6	**11.5**		**5**	**B: 2.2**	64 - 68 HRC	Martensitic
HARDFACE NCWB	**1.1**	0.8	0.8	**22**	**3.5**	**3.5**	W : 6 B : +	64 - 68 HRC	Austenitic

Examples of filler metals with hard carbide phases embedded in a matrix.

Welding Alloys Group

Cobalt base alloy

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), 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. A grade 21 STELLOY is largely insensitive to cracking and offers good impact characteristics. STELLOY 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 self-polishing 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 STELLOY filler metals are welded using a preheating temperature of around 350°C, followed by slow cooling under thermal insulation.

Designation	C	Mn	Si	Cr	W	Fe	Others	Hardness 3 layers As welded	Hardness 3 layers Workhardened
STELLOY 25	0.15	1.5	1	20	14	4	Ni: 9.5	210 HB	40 HRC
STELLOY 21	0.25	1	1	28		4	Ni: 3 Mo: 5.5	33 HRC	47 HRC
STELLOY 6BC	0.9	1	1	28.5	4.5	4		38 HRC	
STELLOY 6	1.05	1	1	28.5	4.5	4		42 HRC	
STELLOY 6HC	1.2	1	1	28.5	4.5	4		44 HRC	
STELLOY 12	1.5	1	1	30	7.5	4		45 HRC	
STELLOY 1	2.3	1	1	28.5	12	4		53 HRC	

Example of "cobalt base alloy" fillers.

Nickel base alloy

The nickel base alloys most commonly used for hardfacing 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) and enables them to maintain their hardness up to 500°C.

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. The table below shows typical products from this family:

Designation	C	Mn	Si	Cr	B	Fe	Hardness 3 layers
STELLOY 40	**0.5**	0.2	2	**12.5**	**2.5**	2.5	40 HRC
STELLOY 50	**0.6**	0.2	4	**11.5**	**2.5**	3.5	50 HRC
STELLOY 60	**0.85**	0.2	4	**14.5**	**3**	4.5	55 - 60 HRC

Example of "nickel base alloy" fillers.

Other nickel base alloys exist which are especially resistant to high temperature stresses and thermal shocks. The addition of chromium, molybdenum, tungsten and cobalt provides them with the ideal properties for open forge hammers. The table below shows typical products in this family:

Designation	C	Mn	Si	Cr	Fe	Mo	W	Others	Hardness 3 layers As welded	Hardness 3 layers Workhardened
STELLOY Ni520	**0.06**	0.2	0.2	**13**	**2.2**	6	0.8	Co: 11.5 Ti: 3 Al: 2	250 HB	400 HB
STELLOY C	**0.05**	0.6	0.5	**16**	**5**	16	4.5		200 HB	320 HB

Example of "nickel base alloy" fillers.

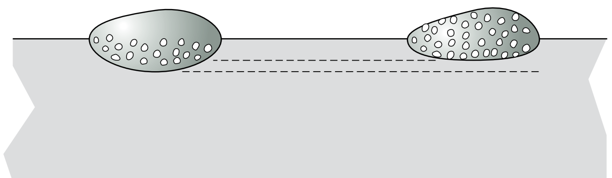
Group 4: Tungsten carbides

Tungsten carbide provides extreme resistance to abrasive wear.

Surfaced layers containing a dispersion of tungsten carbide are produced using a cored wire with a filling of up to 60% of tungsten carbide grains, 100 – 250 microns in size. These pass directly through the welding arc without melting, in contrast to the carbides formed by precipitation in iron and cobalt base hardfacing alloys.

The wire sheath melts to form the matrix of the deposit. Mild steel, stainless steel and nickel base matrices are available.

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.



Representation of the distribution of tungsten carbide in high energy welding (left) and low energy welding (right).

Designation	Matrix	WC	Hardnesses 1 layer	Carbide phase hardness
HARDFACE NICARBW	**Nickel base matrix**	<60	44 - 52 HRC	2000 - 2500 HV
HARDFACE STAINCARBW	**Stainless steel matrix**	<60	45 - 55 HRC	2000 - 2500 HV
HARDFACE STEELCARBW	**Steel matrix**	<60	52 - 62 HRC	950 - 2000 HV

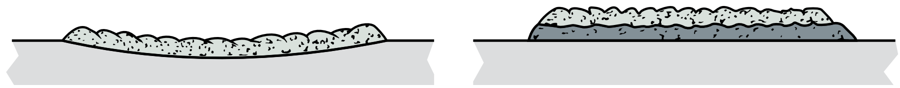
Example of "tungsten carbide alloy" fillers.

6.4. Choosing a buffer layer

Buffer layers are recommended before hardfacing:

- When a metallic transition is required to ensure a sound deposit.
- To optimise the mechanical characteristics of the final hardfacing

Using a low or medium alloy steel for a buffer layer provides an intermediate hardness between the base metal and the hardfacing. This solution should be used to avoid the hardfacing 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 buffer layers are often used. These can absorb the contraction stresses without cracking, largely removing the need for preheat.

One of the following products is usually selected:

- TRI S 309: Austenitic stainless type 309 (23Cr-12Ni)
- TRI S 312: Austenitic stainless type 312 (29Cr-9Ni)
- HARDFACE 19 9 6: Austenitic stainless type 307 (19Cr-9Ni-6Mn)
- HARDFACE AP: Austenitic stainless 14Cr-16Mn

Two alloys are particularly recommended for creating a 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 hardfacing alloys.

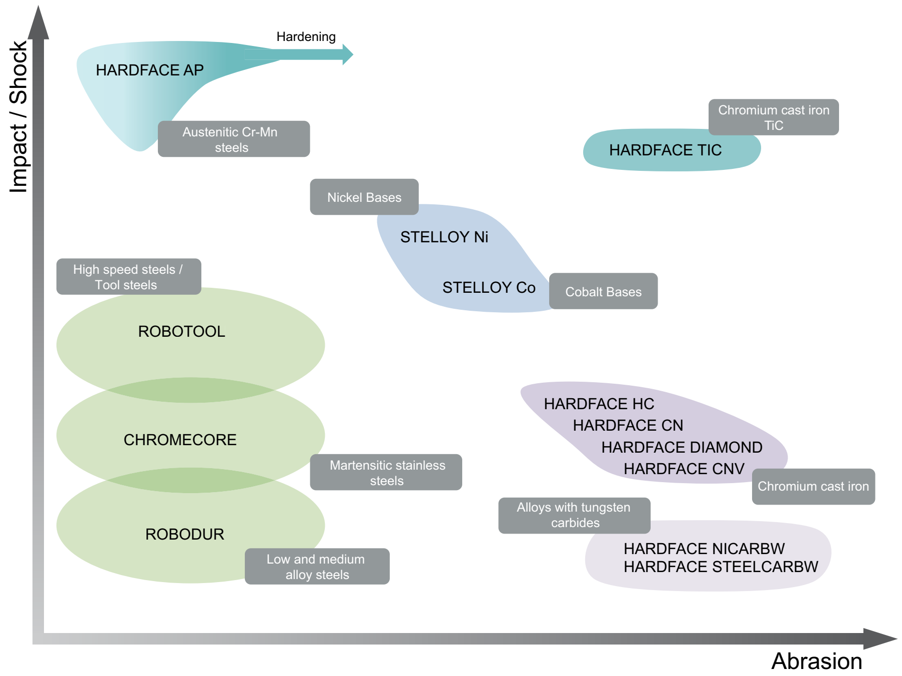
2 - The HARDFACE AP-O is recommended with martensitic hardfacing alloys. As it contains no nickel, there is no risk of softening the hard deposit.

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.

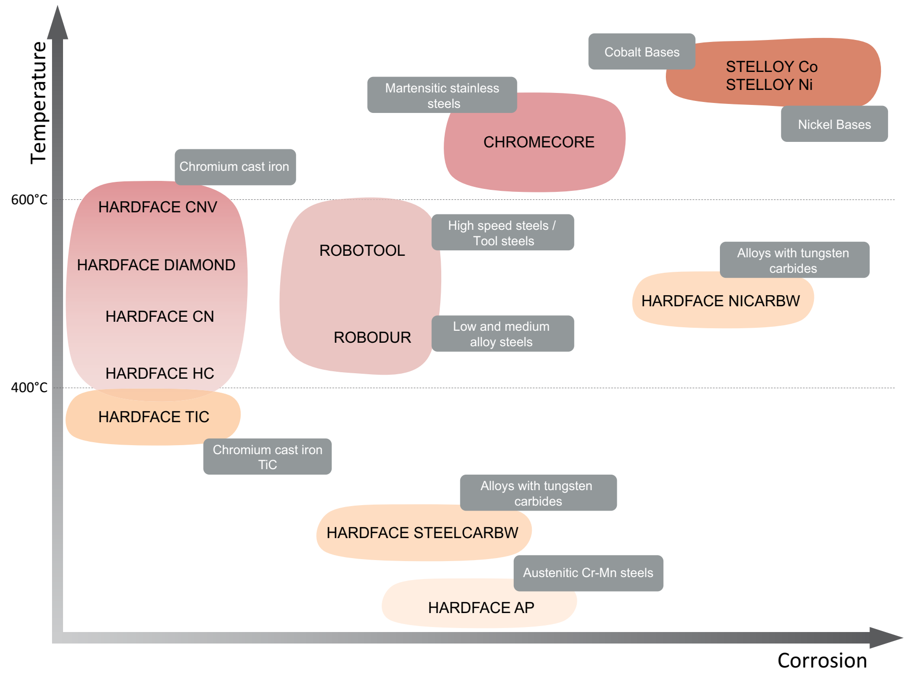
6.5. Choosing the consumable for hardfacing

The two diagrams below and the product selection questionnaire that follows, have been prepared to help find the ideal product for the service conditions and loads:

Primary factors (abrasion and shock)



Secondary factors (temperature and corrosion)



6.6. Product selection questionnaire

Type of wear

- ☐ Low and moderate abrasion/low impact
- ☐ High abrasion/under pressure
- ☐ Severe abrasion/high impact
- ☐ Erosion
- ☐ Combined wear ______
- ☐ Cavitation
- ☐ Thermal fatigue
- ☐ Fretting
- ☐ Corrosion

Description ______

What is the part used for? ______

Problem(s) encountered ______

Current Lifetime ______

Type of part

Industry ______

Dimensions/shape ______

Other (plan/photo) ☐ Yes ☐ No

Desired lifetime ______

Parts rejection criterion ______

Does this part determine the maintenance schedule? ☐ Yes ☐ No

If Yes, other than this part, which other part would determine the new maintenance schedule?

______

How would the maintenance schedule change? ______

Maintenance/repair /hardfacing operation

Welding position ______ Number of parts ______

Accessibility ______ Max. duration of operation ______

Substrate

Base metal ______

Chemical analysis ______

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

Existing surfacing ______

Thickness deposited initially ______

Select the surfacing procedure(s)

☐ TIG ☐ MMA ☐ TE ☐ MIG/MAG ☐ SAW

☐ Manual ☐ Automatic

☐ Semi-automatic ☐ Robot

Deposit characteristic

Thickness to be deposited ______

Number of layers ______

State of surface (as welded or machined) ______

Tolerance to cracks ______

Heat treatment after welding

Heating rate (°C/h) ______

Gradient (°C) ______

Cooling rate (°C/h) ______

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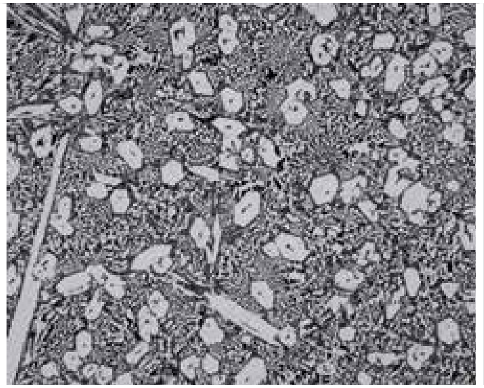
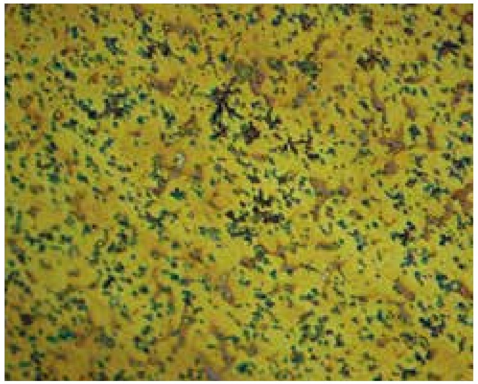
7 Various micrographic structures

Micrographs



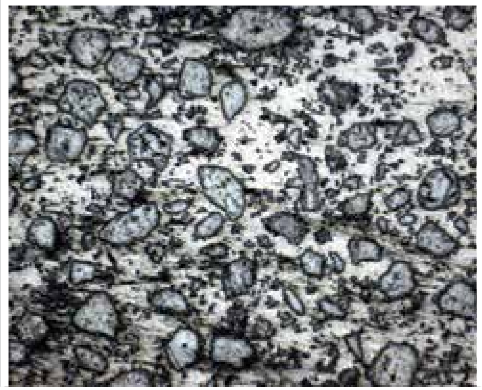
HARDFACE HC-O

Primary chromium carbides
Secondary chromium carbides



HARDFACE TIC-O

Titanium carbide



HARDFACE NICARBW-G

Tungsten carbides
in an Ni-Cr-B-Si matrix

Micrographs

ROBOTOOL 34W-G

After heat treatment (580°C-10h)

Martensitic matrix with residual austenite

STELLOY 6-G

Cobalt matrix with hard phases

CHROMECORE 414N-S

Martensitic structure with less than 7% delta ferrite

8 Examples of industrial applications

Welding Alloys Group

Steel making

Continuous casting roller

CHROMECORE 434N-S
CHROMECORE 414N-S

Continuous casting roller

CHROMECORE 434DN-O
CHROMECORE 414DN-O

Agglomerate star breaker
HARDFACE CNV-O

Steel making

Blast furnace cone

HARDFACE CN-O
HARDFACE CNV-O

Forge

Forging die

HARDFACE DCO-G

Open die press

STELLOY C-G
+ STELLOY Ni520-G

Examples of industrial applications

Thermal power plants

Crusher roller

HARDFACE HC-O
HARDFACE CN-O
HARDFACE CNV-O
HARDFACE DIAMOND

Crusher ring

HARDFACE HC-O
HARDFACE CN-O
HARDFACE CNV-O
HARDFACE DIAMOND

Distribution cone

HARDFACE HC-O
HARDFACE CN-O
HARDFACE CNV-O

Cement works

Crusher roller

HARDFACE HC-O
HARDFACE CN-O
HARDFACE CNV-O
HARDFACE DIAMOND

Crusher disc

HARDFACE TIC-O

Rebuilt furnace support roller

GAMMA 182

Examples of industrial applications

Mining and quarrying

Crusher

HARDFACE TIC-O
HARDFACE CN-O

Gears

HARDFACE T-O
HARDFACE AP-O

Bucket wheel

HARDFACE HC-O
HARDFACE
STAINCARB W-O
HARDFACE NICARBW-G

Sugar plants

Sugar cane crusher roll

HARDFACE BUF-O
HARDFACE UCW-O
MAX EXTRACT

Sugar cane crusher roll

HARDFACE BUF-O
HARDFACE UCW-O
MAX EXTRACT PLUS

Crusher hammers

HARDFACE TIC-O

Examples of industrial applications

Brickmaking

Screw conveyor

HARDFACE HC-O
HARDFACE CNV-O
HARDFACE NICARBW-G

Feeder cone

HARDFACE HC-O

Recycling and environment

Roller press

HARDFACE 167Nb-S
HARDFACE TICM-O

Recycling and environment

Tyre grinder

HARDFACE AP-O
+ HARDFACE TIC-O

Sludging

Pump housing

HARDFACE HC-O

Pipework and elbow

HARDFACE TIC-O
HARDFACE HC-O
HARDFACE CN-O
HARDFACE
STAINCARBW-O
HARDFACE NICARBW-G

Examples of industrial applications

Railways

Rail crossing

HARDFACE APRAIL-O

Tramway curve

HARDFACE 19 9 6-S

Rail head

HARDFACE TLN-O

Hydroelectric plant

Bucket of a pelton wheel

CAVITALLOY

Kaplan turbine blade

TETRA V 309L-G
+ CAVITALLOY

Kaplan turbine housing

TETRA V 316L-G

9 Our automated hardfacing machines

WA Machines

FROG TOP RAIL

Automated weld restoration of worn frogs and rails

H-FRAME

Facilitates the surfacing jobs of all kind of parts in workshop

Multiple configurations possible: rotating table, manipulator, lathe etc.

SCREWFLIGHT

Hardfacing of the different parts of a screw: shaft, filet, flight and outside of the screw.

WA Machines

ROLL CLADDER

Hardfacing of continuous casting rollers (self-shielded cored wire or submerged arc welding process)

PLATE CLADDER

Plate hardfacing applications with multiple welding heads.

The clamping table is designed to limit deformation and finishing

ROTARY PLATE CLADDER

Plate hardfacing applications with multiple welding heads.

The plates are rolled for the hardfacing operation and then straightened back.

Our automated hardfacing machines

WA Machines

FROG TOP RAIL

H-FRAME

SCREWFLIGHT

WA Machines

ROLL CLADDER

PLATE CLADDER

ROTARY PLATE CLADDER

Notes

Notes

Notes

Hardness conversion table

(in accordance with ASTM E 140)

HRC	HV	HB Standard
68	940	-
67	900	-
66	865	-
65	832	-
64	800	-
63	772	-
62	746	-
61	720	-
60	697	-
59	674	-
58	653	-
57	633	-
56	613	-
55	595	-
54	577	-
53	560	-
52	544	500
51	528	487
50	513	475
49	498	464
48	484	451
47	471	442
46	458	432
45	446	421
44	434	409
43	423	400
42	412	390
41	402	381
40	392	371
39	382	362
38	372	353
37	363	344
36	354	336
35	345	327
34	336	319
33	327	311
32	318	301
31	310	294
30	302	286
29	294	279
28	286	271
27	279	264
26	272	258
25	266	253

HRC	HV	HB Standard
24	260	247
23	254	243
22	248	237
21	243	231
20	238	226
	222	222
	216	216
	210	210
	205	205
	200	200
	195	195
	190	190
	185	185
	180	180
	176	176
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	114	114
	112	112
	110	110
	108	108
	107	107

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of advanced welding
consumables

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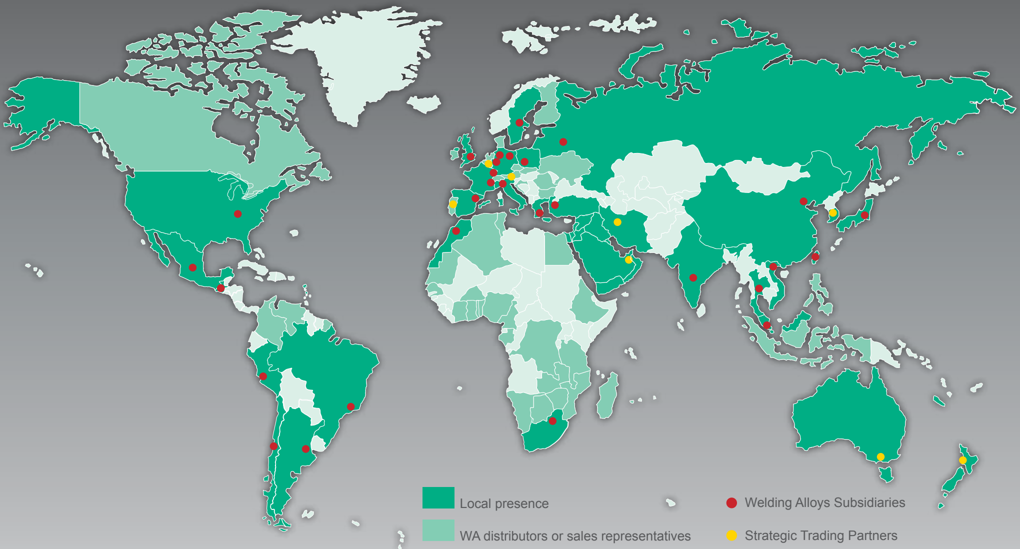

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