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

Written by:
Bastien GERARD  Welding Engineer, WELDING ALLOYS France

With the participation of:
Lauren CALVERT  Marketing Executive, WELDING ALLOYS GROUP
Mario CORDERO  Manager R&D, WELDING ALLOYS GROUP
Clive PEASE  Development Engineer, WELDING ALLOYS France
Matt REIFF  Welding Engineer / Commercial Sales Manager, WELDING ALLOYS USA, Inc.
1. What is wear? 4
  1.1. Definition 4
  1.2. Mechanisms 4

2. Different types of wear 5
  2.1. Low and moderate stress abrasion / low impact 5
  2.2. High stress abrasion / under pressure 6
  2.3. Severe abrasion (gouging) / high impact 6
  2.4. Adhesion / friction 7
  2.5. Erosion 7
  2.6. Cavitation 8
  2.7. Thermal fatigue 9
  2.8. Fretting 9
  2.9. Corrosion 9
  2.10. Combined wear 10
  2.11. Summary table 11

3. Hardfacing terminology 12
  3.1. Rebuilding 12
  3.2. Buffer layer 13
  3.3. Hardfacing 13

4. Hardfacing by arc welding 14
  4.1. Benefits of hardfacing 14
  4.2. Hardfacing welding procedures 14
  4.3. Dilution 18
  4.4. Bead patterns 19
  4.5. Shrinkage cracks 22
  4.6. Preheating temperature 22

5. Characterisation tests for your hardfacing 26
  5.1. Characterising the base metal: sparking and magnetism 26
  5.2. Hardness tests 28
  5.3. Abrasion tests 30
  5.4. Die penetrant testing 32

6. Choosing the right hardfacing consumable 33
  6.1. Standard classifications according to EN 14700 33
  6.2. Description of the elements 34
  6.3. Classification by product family 36
  6.4. Choosing a buffer layer 44
  6.5. Choosing the right consumable for hardfacing 46
  6.6. Product selection questionnaire 48

7. Various micrographic structures 50

8. Examples of industrial applications 52

9. Our automated hardfacing machines 62
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 result 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.

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.
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, corrosion 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Diagram</th>
<th>Damage observed</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate stress abrasion/low impact</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Cutting Micromachining Scratches</td>
<td></td>
</tr>
<tr>
<td>High stress abrasion/under pressure</td>
<td><img src="image2.png" alt="Diagram" /></td>
<td>Deformation Gouged chips</td>
<td>60 %</td>
</tr>
<tr>
<td>Severe stress abrasion (gouging)/high impact</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td>Scratches Large chips gouged out Deformation</td>
<td></td>
</tr>
<tr>
<td>Adhesion/Friction</td>
<td><img src="image4.png" alt="Diagram" /></td>
<td>Transfer of material</td>
<td>15%</td>
</tr>
<tr>
<td>Erosion</td>
<td><img src="image5.png" alt="Diagram" /></td>
<td>Micromachining Change of surface texture</td>
<td>7%</td>
</tr>
<tr>
<td>Cavitation</td>
<td><img src="image6.png" alt="Diagram" /></td>
<td>Loss of material</td>
<td>3%</td>
</tr>
<tr>
<td>Thermal fatigue</td>
<td><img src="image7.png" alt="Diagram" /></td>
<td>Thermal fatigue cracking</td>
<td>10%</td>
</tr>
<tr>
<td>Fretting</td>
<td><img src="image8.png" alt="Diagram" /></td>
<td>Pitting - Chipping Deformation - Impressions</td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td><img src="image9.png" alt="Diagram" /></td>
<td>Fouling, loss of material, etc.</td>
<td>5%</td>
</tr>
</tbody>
</table>
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 applied 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.).
<table>
<thead>
<tr>
<th>Full name</th>
<th>Abbreviation</th>
<th>Designation EN ISO 4063</th>
<th>Type</th>
<th>Precautions</th>
<th>Weld pool protection</th>
<th>Dilution</th>
<th>Typical deposit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas tungsten arc welding</td>
<td>TIG</td>
<td>141/143</td>
<td>Manual/Automatic</td>
<td>Electric arc</td>
<td>Gas</td>
<td>5 - 15%</td>
<td>0.5 - 1.5 kg/h</td>
</tr>
<tr>
<td></td>
<td>GTAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.1 - 3.3 lb/h</td>
</tr>
<tr>
<td>Shielded metal arc welding</td>
<td>MMA</td>
<td>111</td>
<td>Manual</td>
<td>Electric arc</td>
<td>Baking slag</td>
<td>15 - 30%</td>
<td>1.0 - 3.0 kg/h</td>
</tr>
<tr>
<td></td>
<td>SMAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.2 - 6.6 lb/h</td>
</tr>
<tr>
<td>Arc welding with tubular</td>
<td>TE</td>
<td>/</td>
<td>Manual</td>
<td>Electric arc</td>
<td>-</td>
<td>8 - 30%</td>
<td>2.0 - 4.0 kg/h</td>
</tr>
<tr>
<td>electrode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.4 - 8.8 lb/h</td>
</tr>
<tr>
<td>Gas shielded metal arc welding</td>
<td>MAG</td>
<td>136/138</td>
<td>Semi-automatic/Automatic</td>
<td>Electric arc</td>
<td>Gas</td>
<td>15 - 35%</td>
<td>3.0 - 10.0 kg/h</td>
</tr>
<tr>
<td>with cored wire</td>
<td>FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.6 - 22 lb/h</td>
</tr>
<tr>
<td>Arc welding with self-protecting</td>
<td>FCAW</td>
<td>114</td>
<td>Semi-automatic/Automatic</td>
<td>Electric arc</td>
<td>With or without slag</td>
<td>15 - 35%</td>
<td>3.0 - 12.0 kg/h</td>
</tr>
<tr>
<td>cored wire (no protective gas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.6 - 26.4 lb/hr</td>
</tr>
<tr>
<td>Submerged arc welding</td>
<td>SAW</td>
<td>12-</td>
<td>Automatic</td>
<td>Flux baking</td>
<td>Slag</td>
<td>30 - 50%</td>
<td>5.0 - 20.0 kg/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.0 - 44 lb/h</td>
</tr>
</tbody>
</table>

**Designation**

- **EN ISO 4063**
- **Typical deposit rate**
- **Full name**
- **Abbreviation**
- **Designation EN ISO 4063**
- **Type**
- **Precautions**
- **Weld pool protection**
- **Dilution**
- **Typical deposit rate**
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.

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

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.

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.
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.

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.

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.
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:

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:

\[
\text{Ceq} = \frac{\% \text{C}}{6} + \frac{\% \text{Mn}}{5} + \frac{\% \text{Cr} + \% \text{Mo} + \% \text{V}}{15} + \% \text{Ni} + \% \text{Cu}
\]
The table below gives approximate preheating temperatures required for the various base metals:

<table>
<thead>
<tr>
<th>Carbon equivalent</th>
<th>Weldability</th>
<th>Preheating</th>
<th>Postheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceq &lt; 0.35</td>
<td>Good</td>
<td>Light preheating</td>
<td>Not required</td>
</tr>
<tr>
<td>0.35 &lt; Ceq &lt; 0.6</td>
<td>Acceptable</td>
<td>150 – 250°C</td>
<td>Preferable</td>
</tr>
<tr>
<td>Ceq &gt; 0.6</td>
<td>Precautions are required</td>
<td>&gt; 250°C</td>
<td>Required</td>
</tr>
</tbody>
</table>

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).

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

\[ \text{Preheating} \ T^* = 350 \sqrt{(C)} - 0.25 \]

(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.

\[ \text{CC} = \frac{C + \frac{Mn + Cr}{9} + \frac{Ni}{18} + \frac{7 \text{ Mo}}{90}}{0.005 \times (\text{Substrate thickness in mm}) \times (\text{CC})} \]

\[ (\text{CE}) = (\text{CC}) + (\text{CET}) \]

Seferian diagram.

Flange borehole cladded with STELLOY 6-G.
Automatic weld overlay using TIG hot wire process (STELLOY 6 TIG)
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.

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

*Table: 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 hardness 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.

### Penetraor Brinell Rockwell Vickers

<table>
<thead>
<tr>
<th>Type</th>
<th>Hardened steel / Tungsten carbide</th>
<th>Diamond</th>
<th>Diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Sphere</td>
<td>Cone</td>
<td>Pyramid with square base</td>
</tr>
<tr>
<td>Principle</td>
<td><img src="image" alt="Penetraor" /></td>
<td><img src="image" alt="Load" /></td>
<td><img src="image" alt="Impression" /></td>
</tr>
</tbody>
</table>

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

**ASTM G65 Test (schematic)**

*Adjusted weight loss for three chromium cast iron wires.*

---

**Examples of Vickers hardness values for common materials.**

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Symbol</th>
<th>Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiC</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>TiC</td>
<td>3200</td>
<td></td>
</tr>
<tr>
<td>VC</td>
<td>2900</td>
<td></td>
</tr>
<tr>
<td>NbC</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Cr₂C₃</td>
<td>1350</td>
<td></td>
</tr>
<tr>
<td>Mo₂C</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>WC/W₂C</td>
<td>2000/1800</td>
<td></td>
</tr>
<tr>
<td>Borides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiB₄</td>
<td>3300</td>
<td></td>
</tr>
<tr>
<td>VB₃</td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>NbB₃</td>
<td>2600</td>
<td></td>
</tr>
<tr>
<td>CrB₂</td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>MoB</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td>Nitrides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>3300</td>
<td></td>
</tr>
<tr>
<td>TiN</td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>VN</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>NbN</td>
<td>1400</td>
<td></td>
</tr>
<tr>
<td>CrN</td>
<td>1100</td>
<td></td>
</tr>
</tbody>
</table>

---

1 - abrasive sand
2 - nozzle
3 - rubber lined wheel
4 - specimen
5 - weights

Specimen’s appearance after testing
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.

![Chemical Composition Table](image)

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

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

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Hardnesses &amp; Carbides</th>
<th>Performance at temperature</th>
<th>Resistance to shocks</th>
<th>Ductility</th>
<th>Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C</strong></td>
<td><strong>Carbon</strong> 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.</td>
<td>▲▲▲▲</td>
<td>▲</td>
<td>▼▼▼▼</td>
<td>▼▼▼▼</td>
<td>▼▼</td>
</tr>
<tr>
<td><strong>Cr</strong></td>
<td><strong>Chromium</strong> 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.</td>
<td>▲▲▲▲</td>
<td>▲</td>
<td>▼▼▼▼</td>
<td>▼▼</td>
<td>▲▲▲▲</td>
</tr>
<tr>
<td><strong>Mo</strong></td>
<td><strong>Molybdenum</strong> belongs to the category of elements that increase strength and resistance to corrosion and is therefore often used in Cr-Ni austenitic steels.</td>
<td>▲</td>
<td>▲▲</td>
<td>▲</td>
<td>▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Nb</strong></td>
<td><strong>Niobium</strong> is a powerful generator of hard carbides. This element can also be used as a stabiliser in refractory austenitic steels.</td>
<td>▲▲▲▲</td>
<td>▲▲</td>
<td>▲</td>
<td>▼▼▼▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td><strong>Vanadium</strong> 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.</td>
<td>▲▲</td>
<td>▲</td>
<td>▼</td>
<td>▼▼▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td><strong>Tungsten</strong> is a powerful generator of very hard carbides. This element increases the resistance to high temperatures and is therefore used for tool steel applications.</td>
<td>▲▲▲▲</td>
<td>▲▲▲</td>
<td>▼</td>
<td>▼▼▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Ti</strong></td>
<td><strong>Titanium</strong> combines easily with other elements such as oxygen (deoxidising effect) and carbon. Titanium carbide forms fine particles, providing good resistance to external shocks.</td>
<td>▲▲</td>
<td>▲</td>
<td>▲▲</td>
<td>▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Mn</strong></td>
<td><strong>Manganese</strong> 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.</td>
<td>▲</td>
<td>▲</td>
<td>▲▲</td>
<td>▼▼▼</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Ni</strong></td>
<td><strong>Nickel</strong> 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.</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Co</strong></td>
<td><strong>Cobalt</strong> promotes heat resistance by slowing grain growth. In addition, it provides excellent resistance to corrosion and erosion.</td>
<td>▲</td>
<td>▲▲▲</td>
<td>▲</td>
<td>▲</td>
<td>▲▲▲</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Designation</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>Hardness 3 layers</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>HARDFACE BUF</td>
<td>0.12</td>
<td>1.2</td>
<td>0.5</td>
<td>1.5</td>
<td>+</td>
<td>250 HB</td>
<td>Bainite</td>
</tr>
<tr>
<td>SPEEDARC X121T5-K4</td>
<td>0.07</td>
<td>1.4</td>
<td>0.5</td>
<td>0.55</td>
<td>0.4</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

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.


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.

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

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.
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.

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.

Example of "tool steel" filler metals

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

Example of "austenitic manganese" filler metals

<table>
<thead>
<tr>
<th>Designation</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Hardness 3 layers As welded</th>
<th>Hardness 3 layers Workhardened</th>
</tr>
</thead>
<tbody>
<tr>
<td>HARDFACE NM14</td>
<td>1</td>
<td>14</td>
<td>0.5</td>
<td>200 HB</td>
<td>46 HRC</td>
</tr>
</tbody>
</table>

Example of "tool steel" filler metals

Example of "high alloy" filler metals
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).

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

<table>
<thead>
<tr>
<th>Designation</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>W</th>
<th>Fe</th>
<th>Others</th>
<th>Hardness 3 layers As welded</th>
<th>Hardness 3 layers Workhardened</th>
</tr>
</thead>
<tbody>
<tr>
<td>STELLOY 40</td>
<td>0.5</td>
<td>0.2</td>
<td>2</td>
<td>12.5</td>
<td>2.5</td>
<td>2.5</td>
<td>Ni: 9.5</td>
<td>210 HB</td>
<td>40 HRC</td>
</tr>
<tr>
<td>STELLOY 50</td>
<td>0.6</td>
<td>0.2</td>
<td>4</td>
<td>11.5</td>
<td>2.5</td>
<td>3.5</td>
<td>Ni: 3</td>
<td>33 HRC</td>
<td>47 HRC</td>
</tr>
<tr>
<td>STELLOY 60</td>
<td>0.85</td>
<td>0.2</td>
<td>4</td>
<td>14.5</td>
<td>3</td>
<td>4.5</td>
<td>Co: 11.5</td>
<td>38 HRC</td>
<td>55 - 60 HRC</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Designation</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Fe</th>
<th>Mo</th>
<th>W</th>
<th>Others</th>
<th>Hardness 3 layers As welded</th>
<th>Hardness 3 layers Workhardened</th>
</tr>
</thead>
<tbody>
<tr>
<td>STELLOY Ni520</td>
<td>0.06</td>
<td>0.2</td>
<td>0.2</td>
<td>13</td>
<td>2.2</td>
<td>6</td>
<td>0.8</td>
<td>Co: 11.5</td>
<td>250 HB</td>
<td>400 HB</td>
</tr>
<tr>
<td>STELLOY C</td>
<td>0.05</td>
<td>0.6</td>
<td>0.5</td>
<td>16</td>
<td>5</td>
<td>16</td>
<td>16</td>
<td>Ti: 3</td>
<td>200 HB</td>
<td>320 HB</td>
</tr>
</tbody>
</table>

Example of "nickel base alloy" fillers.

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 hardnnesses 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.

Table: Cobalt base alloys

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

Example of "cobalt base alloy" fillers.

Group 3: Non-ferrous alloy, Cobalt or Nickel base
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

<table>
<thead>
<tr>
<th>Wear Type</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low and moderate abrasion/low impact</td>
<td>☐</td>
</tr>
<tr>
<td>High abrasion/under pressure</td>
<td>☐</td>
</tr>
<tr>
<td>Severe abrasion/high impact</td>
<td>☐</td>
</tr>
<tr>
<td>Erosion</td>
<td>☐</td>
</tr>
<tr>
<td>Combined wear</td>
<td>☐</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wear Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavitation</td>
<td></td>
</tr>
<tr>
<td>Thermal fatigue</td>
<td></td>
</tr>
<tr>
<td>Fretting</td>
<td></td>
</tr>
<tr>
<td>Corrosion</td>
<td></td>
</tr>
</tbody>
</table>

#### What is the part used for?

#### Problem(s) encountered

#### Current Lifetime

#### Type of part

<table>
<thead>
<tr>
<th>Industry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions/shape</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Other (plan/photo)

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Desired lifetime

#### Parts rejection criterion

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Does this part determine the maintenance schedule?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 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

<table>
<thead>
<tr>
<th>Welding position</th>
<th>Number of parts</th>
<th>Accessibility</th>
<th>Max. duration of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Substrate

<table>
<thead>
<tr>
<th>Base metal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Chemical analysis

<table>
<thead>
<tr>
<th>Carbon equivalent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceq = %C + %Mn/6 + %Cr + %Mo + %V/5 + %Ni + %Cu/15</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Existing surfacing</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness deposited initially</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Select the surfacing procedure(s)

<table>
<thead>
<tr>
<th>TIG</th>
<th>MMA</th>
<th>TE</th>
<th>MIG/MAG</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manual</th>
<th>Automatic</th>
<th>Semi-automatic</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Deposit characteristic

<table>
<thead>
<tr>
<th>Thickness to be deposited</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State of surface (as welded or machined)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tolerance to cracks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Heat treatment after welding

<table>
<thead>
<tr>
<th>Heating rate (°C/h)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gradient (°C)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cooling rate (°C/h)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scan me and mail me 📬 marketing@welding-alloys.com
Various micrographic structures

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

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
Examples of industrial applications

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

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**

- **Feeder cone**
  - HARDFACE HC-O
  - HARDFACE CNV-O
  - HARDFACE NICARBW-G

**Recycling and environment**

- **Screw conveyor**
  - HARDFACE HC-O
  - HARDFACE CNV-O
  - HARDFACE NICARBW-G

- **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

- **Feeder cone**
  - 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
Our automated hardfacing machines

- **Frog Top Rail**: Automated weld restoration of worn frogs and rails.
- **H-Frame**: Facilitates the surfacing jobs of all kinds of parts in the 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.
- **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

- FROG TOP RAIL
- H-FRAME
- SCREWFLIGHT
- ROLL CLADDER
- PLATE CLADDER
- ROTARY PLATE CLADDER
# Hardness conversion table

(in accordance with ASTM E140)

<table>
<thead>
<tr>
<th>HRC</th>
<th>HV</th>
<th>HB Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>940</td>
<td>-</td>
</tr>
<tr>
<td>67</td>
<td>900</td>
<td>-</td>
</tr>
<tr>
<td>66</td>
<td>865</td>
<td>-</td>
</tr>
<tr>
<td>65</td>
<td>832</td>
<td>-</td>
</tr>
<tr>
<td>64</td>
<td>800</td>
<td>-</td>
</tr>
<tr>
<td>63</td>
<td>772</td>
<td>-</td>
</tr>
<tr>
<td>62</td>
<td>746</td>
<td>-</td>
</tr>
<tr>
<td>61</td>
<td>720</td>
<td>-</td>
</tr>
<tr>
<td>60</td>
<td>697</td>
<td>-</td>
</tr>
<tr>
<td>59</td>
<td>674</td>
<td>-</td>
</tr>
<tr>
<td>58</td>
<td>653</td>
<td>-</td>
</tr>
<tr>
<td>57</td>
<td>633</td>
<td>-</td>
</tr>
<tr>
<td>56</td>
<td>613</td>
<td>-</td>
</tr>
<tr>
<td>55</td>
<td>595</td>
<td>-</td>
</tr>
<tr>
<td>54</td>
<td>577</td>
<td>-</td>
</tr>
<tr>
<td>53</td>
<td>560</td>
<td>-</td>
</tr>
<tr>
<td>52</td>
<td>544</td>
<td>500</td>
</tr>
<tr>
<td>51</td>
<td>528</td>
<td>487</td>
</tr>
<tr>
<td>50</td>
<td>513</td>
<td>475</td>
</tr>
<tr>
<td>49</td>
<td>498</td>
<td>464</td>
</tr>
<tr>
<td>48</td>
<td>484</td>
<td>451</td>
</tr>
<tr>
<td>47</td>
<td>471</td>
<td>442</td>
</tr>
<tr>
<td>46</td>
<td>458</td>
<td>432</td>
</tr>
<tr>
<td>45</td>
<td>446</td>
<td>421</td>
</tr>
<tr>
<td>44</td>
<td>434</td>
<td>409</td>
</tr>
<tr>
<td>43</td>
<td>423</td>
<td>400</td>
</tr>
<tr>
<td>42</td>
<td>412</td>
<td>390</td>
</tr>
<tr>
<td>41</td>
<td>402</td>
<td>381</td>
</tr>
<tr>
<td>40</td>
<td>392</td>
<td>371</td>
</tr>
<tr>
<td>39</td>
<td>382</td>
<td>362</td>
</tr>
<tr>
<td>38</td>
<td>372</td>
<td>353</td>
</tr>
<tr>
<td>37</td>
<td>363</td>
<td>344</td>
</tr>
<tr>
<td>36</td>
<td>354</td>
<td>336</td>
</tr>
<tr>
<td>35</td>
<td>345</td>
<td>327</td>
</tr>
<tr>
<td>34</td>
<td>336</td>
<td>319</td>
</tr>
<tr>
<td>33</td>
<td>327</td>
<td>311</td>
</tr>
<tr>
<td>32</td>
<td>318</td>
<td>301</td>
</tr>
<tr>
<td>31</td>
<td>310</td>
<td>294</td>
</tr>
<tr>
<td>30</td>
<td>302</td>
<td>286</td>
</tr>
<tr>
<td>29</td>
<td>294</td>
<td>279</td>
</tr>
<tr>
<td>28</td>
<td>286</td>
<td>271</td>
</tr>
<tr>
<td>27</td>
<td>279</td>
<td>264</td>
</tr>
<tr>
<td>26</td>
<td>272</td>
<td>258</td>
</tr>
<tr>
<td>25</td>
<td>268</td>
<td>253</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HRC</th>
<th>HV</th>
<th>HB Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>260</td>
<td>247</td>
</tr>
<tr>
<td>23</td>
<td>254</td>
<td>243</td>
</tr>
<tr>
<td>22</td>
<td>248</td>
<td>237</td>
</tr>
<tr>
<td>21</td>
<td>243</td>
<td>231</td>
</tr>
<tr>
<td>20</td>
<td>238</td>
<td>226</td>
</tr>
<tr>
<td>22</td>
<td>222</td>
<td>222</td>
</tr>
<tr>
<td>21</td>
<td>216</td>
<td>216</td>
</tr>
<tr>
<td>20</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>19</td>
<td>205</td>
<td>205</td>
</tr>
<tr>
<td>18</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>17</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>16</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>15</td>
<td>185</td>
<td>185</td>
</tr>
<tr>
<td>14</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>13</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>12</td>
<td>172</td>
<td>172</td>
</tr>
<tr>
<td>11</td>
<td>169</td>
<td>169</td>
</tr>
<tr>
<td>10</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>9</td>
<td>162</td>
<td>162</td>
</tr>
<tr>
<td>8</td>
<td>159</td>
<td>159</td>
</tr>
<tr>
<td>7</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>6</td>
<td>153</td>
<td>153</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>147</td>
<td>147</td>
</tr>
<tr>
<td>3</td>
<td>144</td>
<td>144</td>
</tr>
<tr>
<td>2</td>
<td>141</td>
<td>141</td>
</tr>
<tr>
<td>1</td>
<td>139</td>
<td>139</td>
</tr>
<tr>
<td>0</td>
<td>137</td>
<td>137</td>
</tr>
<tr>
<td>-1</td>
<td>135</td>
<td>135</td>
</tr>
<tr>
<td>-2</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>-3</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>-4</td>
<td>127</td>
<td>127</td>
</tr>
<tr>
<td>-5</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>-6</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>-7</td>
<td>121</td>
<td>121</td>
</tr>
<tr>
<td>-8</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>-9</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>-10</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>-11</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>-12</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>-13</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>-14</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>-15</td>
<td>107</td>
<td>107</td>
</tr>
</tbody>
</table>
Our Technical ‘Spark’ Solves Your Industrial Challenges

WA Consumables
The go-to provider of advanced welding consumables

WA Machines
The go-to provider of engineered wear protection solutions

WA Integra™
The go-to provider of engineered wear protection solutions

www.welding-alloys.com