Alloy Steels

Weld Tech News

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WELD TECH NEWS is a newsletter for welders working primarily in maintenance and repair. Each issue contains useful information on materials (cast irons, steels, aluminum, copper alloys, etc.), welding products and welding techniques. By collecting each issue, the reader will soon have a handy reference manual covering all aspects of welding, brazing and soldering for maintenance and repair.

ALLOY STEELS

Carbon steels are defined by their carbon content, which is their primary alloy. A carbon content ranging from 0.15 to 1.00% generally encompasses the four basic categories of carbon steels – low, medium, high and low alloy. Small amounts of manganese, copper and silicon are also present in carbon steels. When small amounts of other alloys are added to a carbon steel, we then start creating a class of steels described as low alloy steels.

Low alloy steels are low carbon steels with an additional alloy content of less than 5%. These additional alloys or elements give the carbon steel special mechanical and physical properties.

Adding elements such as nickel, chromium, molybdenum and greater amounts of silicon and manganese to carbon steel give certain qualities to that steel. The principal advantage of low alloy steels is that they respond to heat treatment as well as being strong and tough.

Iron is the main ingredient of steel. By itself iron lacks strength, is soft and does not respond to heat treatment. It is other elements that give steel its mechanical properties.

Manganese is present in all steels. Manganese in steel is next to carbon in importance. It is a deoxidizer, gives strength and makes steel respond to heat treatment. Silicon is also a deoxidizer and contributes to tensile strength. Copper improves resistance to atmospheric corrosion and increases yield and tensile strengths.

These elements are in carbon steels in minimal amounts, usually less than 1%.

"Alloy steels" contain other alloys and higher alloy percentages than the carbon steels. Low alloy steels are considered to have good weldability but not as good as mild steels. Their higher degree of hardness is the main problem in welding them.
Adding nickel to steel makes it tougher and more impact resistant. It increases strength at low temperatures and aids corrosion resistance. It also increases hardenability. Additions of nickel are usually from 1 to 4%. Common high alloy stainless steel types such as 304 or 316 have 8 to 14% nickel.

Chromium in steels make it more responsive to heat treatment. The depth of hardness penetration is also increased. Low alloy steels can contain 0.50 to 1.50% chromium. The chromium in low alloy steels also increases its tensile strength and resistance to atmospheric corrosion. By comparison, stainless steels have larger chromium contents of 12 to 25%.

Molybdenum is another element that increases steel toughness and hardness. At high temperatures it aids in steel's resistance to softening. Usually relatively small quantities of 0.10 to 0.40% are added to alloy steels.

Silicon and manganese are components of regular carbon steels. The silicon content is typically less than 0.60%, the manganese content usually around 1.65%.

As with carbon steels, silicon acts as a deoxidizer and improves properties such as tensile strength and hardenability. In alloy steels the percentage can go to 2.5%.

In low alloy steels as in carbon steels, manganese acts as a deoxidizer, gives added strength and improves steel's responsiveness to heat treating. Some manganese alloy steels can have up to 14% manganese.

**TYPES OF ALLOY STEELS**

*High-Strength Low Alloy (HSLA) -* This class of steels is intended to satisfy certain mechanical properties and not necessarily a chemical composition. They also may have more resistance to corrosion from the atmosphere than regular steels. The chemical composition of these steels is different than those of structural carbon steels, due to the additional alloys. Various alloys and combinations such as chromium, molybdenum, copper, nickel and vanadium are used. The carbon content is kept low which makes for good weldability.

These steels also feature high yield strengths usually exceeding 90,000 p.s.i., high ductility and impact resistance. Cor-Ten® is a commercial name for an alloy of this type. These alloys are used for structures, railroad equipment, bridges, boats and tanks.

*Quenched and Tempered Steels -* These steels are heat treated and provide high tensile and yield strengths as well as good notch toughness, corrosion resistance and ductility. These alloy steels are treated at the steel mill for optimum properties. The carbon content does not normally exceed 0.25% so weldability is good with joint thickness and specific chemical composition being important considerations for procedure. These steels come primarily in the form of plate. A common commercial type of this steel is T-1®. These steels are used in pressure vessels, steel mill equipment, ships, heavy equipment and bridges.

Another type of steel in this group is AR® plate which is a modification to achieve high hardness. These steels have high yield strengths but hardness is their main characteristic. The number indicates the Brinell
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hardness. For example, AR400 would indicate a 400 Brinell hardness. These steels are used in chutes, buckets and truck beds.

*Heat Treatable Low Alloy Steels (HTLA)* - These steels feature enough alloy and carbon content to give them a high degree of hardness with heat treatment. The carbon content ranges from about 0.25% to 0.45% which is higher than that of the quenched and tempered steels and the HSLA steels. The alloy content of chrome and molybdenum classifies them as "chrome-moly's" but the carbon content and hardenability are the defining characteristic of these steels. A typical chrome content would be 0.80% to 1.1 % with moly being 0.15% to 0.25%. It is generally necessary to preheat these steels for welding to get a good weld and avoid cracking. Heat treatment can achieve high strengths as well as hardness. AISI designations 4130, 4140 and 4340 are common types of these steels. Piping, shafts, tubing and aircraft parts are common applications of these steels.

*Chromium-Molybdenum Steels* - These steels generally have lower carbon and higher alloy contents than the HTLA members of the chrome-moly family. Carbon contents are usually less than 0.20%. The chromium content can range from 0.5% to 9% and the molybdenum from 0.5% to 1%. The chromium gives better corrosion and oxidation resistance while the molybdenum provides strength at high temperatures. These characteristics basically increase as the alloy content increases.

Some alloys may contain small amounts of columbium, vanadium or titanium. Castings may have higher carbon contents. These steels are hardenable and preheat is usually required. Common applications are in elevated temperature situations such as steam generating stations and petroleum refining. A common type available in the form of tube, plate, pipe, forging or casting would be a 1-1/4 Cr- 1/2 Mo.

*Nickel Steels* - Additions of 2% to 4% nickel to steel improves its corrosion resistance as well as strength and hardenability. Toughness and impact strength at low temperatures is greatly improved. Primary applications are for pressure vessels. Carbon content over 0.18% will require preheat to weld thick sections.

*Chromium Steels* - Chromium in a low alloy steel increases atmospheric corrosion resistance as well as strength and degree of hardness. Carbon content above 0.18% increases hardenability requiring preheat and maybe postheat.

*Free Machining Steels* - The addition of elements such as lead, sulfur, phosphorous or selenium to low alloy or stainless steels greatly improves their machinability but makes them very difficult to weld. These elements have very low melting points compared to the steel which causes hot cracking.

A future issue of Weld Tech News will cover types of steels that can be considered "high alloy" steels.

**WELDING PROCEDURES**

The weldability of a steel can be described as its ability to resist cracking in the weld area. Proper procedures can be critical to an effective weld regardless of the welding alloy used. The main factor affecting the weldability of the carbon steels is the carbon content. The higher the carbon content of a
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Steel, the more difficult it is to weld. Generally alloy steels have low carbon contents but the alloying elements used in these steels can affect their susceptibility to cracking. The combinations of alloys and their percentages are important factors. Also important is the thickness of the base metal. These factors determine preheat requirements. Another factor that requires attention is the avoidance of weld metal contamination.

Hydrogen contamination of the weld is to be avoided in welding alloy steel as it can cause the weld to crack. Moisture on the base metal or flux of the electrode can introduce hydrogen into the weld. Hydrocarbons can also break down in the heat of the arc and introduce hydrogen into the weld. Sources of hydrocarbons are solvents, machining oils, lubricants and other surface residuals. Rust, dirt and scale need to be removed to avoid porosity in the weld which leads to cracking. The weld area needs to be clean.

The main factors affecting preheat requirements are the alloy content and base metal thickness. Some alloys may require preheat no matter what the thickness and some only for welding thicker sections. The welding process used can also be a factor. Postweld heating of appropriate alloys is done to achieve certain mechanical properties. The following common alloy steel types require special attention to preheat requirements:

![PREHEATING]

<table>
<thead>
<tr>
<th>Type of Metal</th>
<th>Preheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Alloy Nickel Steel</td>
<td>Room Temperature 500°F (260°C)</td>
</tr>
<tr>
<td>Less than ¼&quot; (6.4 mm) thick</td>
<td></td>
</tr>
<tr>
<td>More than ¼&quot; (6.44 mm) thick</td>
<td></td>
</tr>
<tr>
<td>Low Alloy Nickel Chrome Steel</td>
<td>200-300°F (93-150°C)</td>
</tr>
<tr>
<td>Carbon content below .20%</td>
<td>600-800°F (315-425°C)</td>
</tr>
<tr>
<td>Carbon content .20% to .35%</td>
<td>900-1100°F (480-595°C)</td>
</tr>
<tr>
<td>Carbon content above .35%</td>
<td></td>
</tr>
<tr>
<td>Low Alloy Manganese Steel</td>
<td>400-600°F (205-315°C)</td>
</tr>
<tr>
<td>Low Alloy Chrome Steel</td>
<td>Up to 750°F (400°C)</td>
</tr>
<tr>
<td>Low Alloy Molybdenum Steel</td>
<td>Room Temperature 400-650°F (205-345°C)</td>
</tr>
<tr>
<td>Carbon content below 15%</td>
<td></td>
</tr>
<tr>
<td>Carbon content above 15%</td>
<td></td>
</tr>
<tr>
<td>Low Alloy High Tensile Steel</td>
<td>150-300°F (66-150°C)</td>
</tr>
</tbody>
</table>

The High-Strength Low Alloy Steels (HSLA) may require minimum preheats to control the cooling rate of the weld and minimize stresses created from the welding heat. Low hydrogen procedures should be
followed. A typical example is a ASTM A588 type structural steel 1.5 inches thick would require a minimum 150 degree preheat.

As the name implies preheat for the Quenched and Tempered steels can affect the properties of the base metal so specific recommendations should be followed. As usual preheat is advised on thick or highly restrained joints. Preheating should not exceed the previous tempering of the base metal. Preheating of T-1® steel is usually preferred to slow the cooling rate and relieve stresses in the weld zone, 200 degrees for a one inch thickness being an example.

The Heat-Treatable Low Alloy (HTLA) steels demand preheat considerations as well as postheat procedures if specific mechanical requirements of the weld zone are to be met. A heat treatable steel will respond to the heat of welding just like it would respond to an actual heat treatment. If the base metal was heat treated prior to welding it may be hardened. A filler metal that responds to heat treatment may or may not be necessary depending on the application. If welding a HTLA steel to a straight carbon steel, a heat treatable deposit is not a consideration, but preheat is. A minimum preheat of 300 degrees would be a basic rule for the common HTLA steels to avoid cracking of welds.

Chromium-Molybdenum steels generally require preheat to avoid cracking and hardening of the heat affected zone. As the alloy content and/or base metal thickness increases the need for preheat increases. Thickness over 0.5 inch may require a minimum of 200 degrees.

<table>
<thead>
<tr>
<th>AISI Steel</th>
<th>Thickness Range, in.</th>
<th>Minimum Preheat and Interpass Temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>4130</td>
<td>Up to 0.5</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>0.6 - 1.0</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>1.1 - 2.0</td>
<td>450</td>
</tr>
<tr>
<td>4140</td>
<td>Up to 0.5</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>0.6 - 1.0</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>1.1 - 2.0</td>
<td>500</td>
</tr>
<tr>
<td>4340</td>
<td>Up to 2.0</td>
<td>550</td>
</tr>
</tbody>
</table>

**WELDING ALLOYS FOR ALLOY STEELS**

The following are some general filler metal recommendations. Some applications may require more specific recommendations. The welding process used also needs to be considered for practicality and end results.
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**Brutus - AAA** (127,000 p.s.i.) and **Brutus-A** (125,000 p.s.i.) electrodes are chrome-nickel alloys suitable for a variety of alloy steel applications including hardened steels, HTLA types and Chrome-Moly. Their strength and 35% elongation make them ideal for joining dissimilar combinations such as alloy steels to carbon steels. Also available in TIG and MIG wire.

**Polaris - AAA** (98,000 p.s.i.) and **Polaris-A** (95,000 p.s.i.) are the low hydrogen choice electrode for a wide variety of alloy steel applications. They can be used to weld HSLA steels such as Cor-Ten®, and Quenched and Tempered steels such as T-1® and AR® plate. Suitable also for many Chrome-Moly applications. The high elongation of these deposits can often overcome preheats or weld stress problems. Ideal for applications involving impact, thermal stress or vibration.

**Gemini-E** (85,000 p.s.i.) is a high chrome-nickel electrode ideal for welding of Chrome-Moly, HTLA, nickel and chromium steels. Service involving cyclical temperatures should be avoided. Also available in TIG wire.

**Tartan-Tig** (95,000 p.s.i.) is the choice for HTLA steel applications such as 4130, 4140, and 4340. A deposit of this alloy will respond to heat treatment. It also has many HSLA, Q&T and Chrome-Moly uses. Ideal for welding alloy steel tubing. May be blued or plated.

**Tartan-Tig-B** (80,000 p.s.i.) offers good fluidity and maximum machinability. Suitable for HSLA steels.

**Tartan-Mig** (80,000 p.s.i.) is a copper flashed wire with a high alloy content ideal for HSLA steel applications as found in structural steels. Its deoxidizers make it the choice for situations involving steels contaminated by rust, oil or dirt.

**Polaris-Mig** (100,000 p.s.i.) is a high strength joining wire with a low carbon content. For HSLA steels such as Cor-Ten® and the Q&T steels such as T-1® and AR® plate.

This alloy is also the choice for the HTLA steels 4130, 4140 and 4340 as well as many Chrome-Moly types. It features excellent running characteristics.

**Polaris Maximum Shield** (90,000 p.s.i.) is a flux core, gas shielded joining wire that delivers high strength and elongation with superior operating characteristics. Excellent for repair applications due to its active flux it can be used to weld HSLA steels including Cor-Ten®. Ideal for heavy equipment repairs on the T-1® and AR® type steels, its good ductility handles stress and impact. Superior for out of position welding.

**Polaris Ultra Flux Core** (95,000 p.s.i.) is a self shielded flux core wire suitable for welding the HSLA type steels. It can also be used for joining some of the Q&T type wear steels. It exhibits excellent running characteristics.

**Tartan-G** (95,000 p.s.i.) is for gas fusion welding of the HTLA steels. It can be heat treated with the base metal. The deposit is machinable and responds to bluing and plating.
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**Brutus-G** (100,000 p.s.i.) is a low melting temperature flux coated brazing alloy with a low silver content, which aids in wetting action and allows for thin flow joints. Its high strength makes it suitable for brazing of alloy tubing where the heat treatment of the weld deposit is not required.

![](image)

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