Understanding the vital importance of Pre-heat and Post-heat when welding higher-strength steels

Barry Robinson
0272864722
Barry@safegroup.co.nz

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Too often, the welder and those responsible for the welder's actions are unaware of the importance of basic heat treatment understanding in making a successful long-lasting weld on high-strength or high-hardened steels.

The Quarry and Mining industries are full of these 'exotic' steels that require particular care when welding – or indeed ***when applying heat in any form above 400degC***, such as Gas cutting, Plasma or Laser cutting, Flame cutting, and even heavy grinding.

This presentation focusses on the importance of Pre-Heat and Post-Heat during welding. Because welding involves melting two or three different pieces of steel together, a welder becomes a Steelmaker, Steel-Caster, and most importantly, a Heat-Treater.

The 2 basic steps of Hardening and Tempering:

Step 1. Hardening

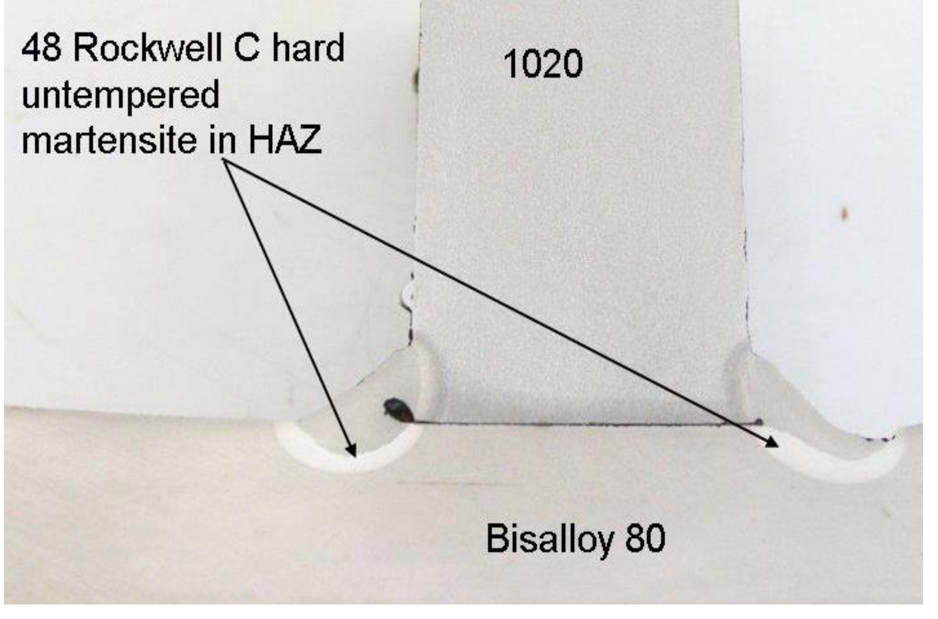
Steel is hardened by heating to approx 850degC "Cherry-red" to change the structure to "Austenite". The hot steel is then cooled quickly, usually quenched in a liquid.

This creates "quenched martensite", a hard, brittle and structurally useless and dangerous condition. Hardening must be followed immediately by <u>tempering</u> to make it tough.

Oil-quenching from 900degC

Under the microscope untempered martensite shows up white. Untempered Martensite is a hard and brittle structure, caused by welding and sometimes small cracks will form in it – leading directly to failure.

In the picture below you can clearly see the white band of brittle martensite in the Bisalloy80. But take note that the 'mild steel' 1020 material also has a small amount in it.



Small cracks can form in hard brittle martensite:

Figure 10: Crack initiating in the HAZ under the weld, 50x, 2% Nital

So after **Quenching** (making the steel hard and brittle by creating **quenched martensite**), the heat-treater must always **Temper** the steel, thus changing the dangerous Quenched Martensite into the most desirable structure: ‘**Tempered Martensite**’

Tempering is Step 2….

Step 2. Tempering

Tempering is re-heating the hardened steel to a temperature usually between 200 and 650 degC.
On a pre-ground surface, 200degC is a pale ‘straw’ colour, and 650degC is a barely-visible dull red colour in a dim ambient light.

As a rough guide for tempering temperatures:
Bisalloy 80: 550degC
Wear Steel G360/G450: 450degC
Wear Steel G500: 370degC

Tempering does these 3 vital things:

1. Changes the brittle quenched martensite to tough tempered martensite – the toughest & most desirable structure.

2. Lowers the hardness to that which is required by the application.

3. Relieves the quenching stresses.

The properly hardened and tempered structure is a mandatory requirement for:

> Good impact strength

> Good fatigue life

> Good tough tensile strength.

So how does this apply to Welding?

Following is the explanation of how a welder is an unwitting heat-treater.

A welder is a ***Heat-Treater***

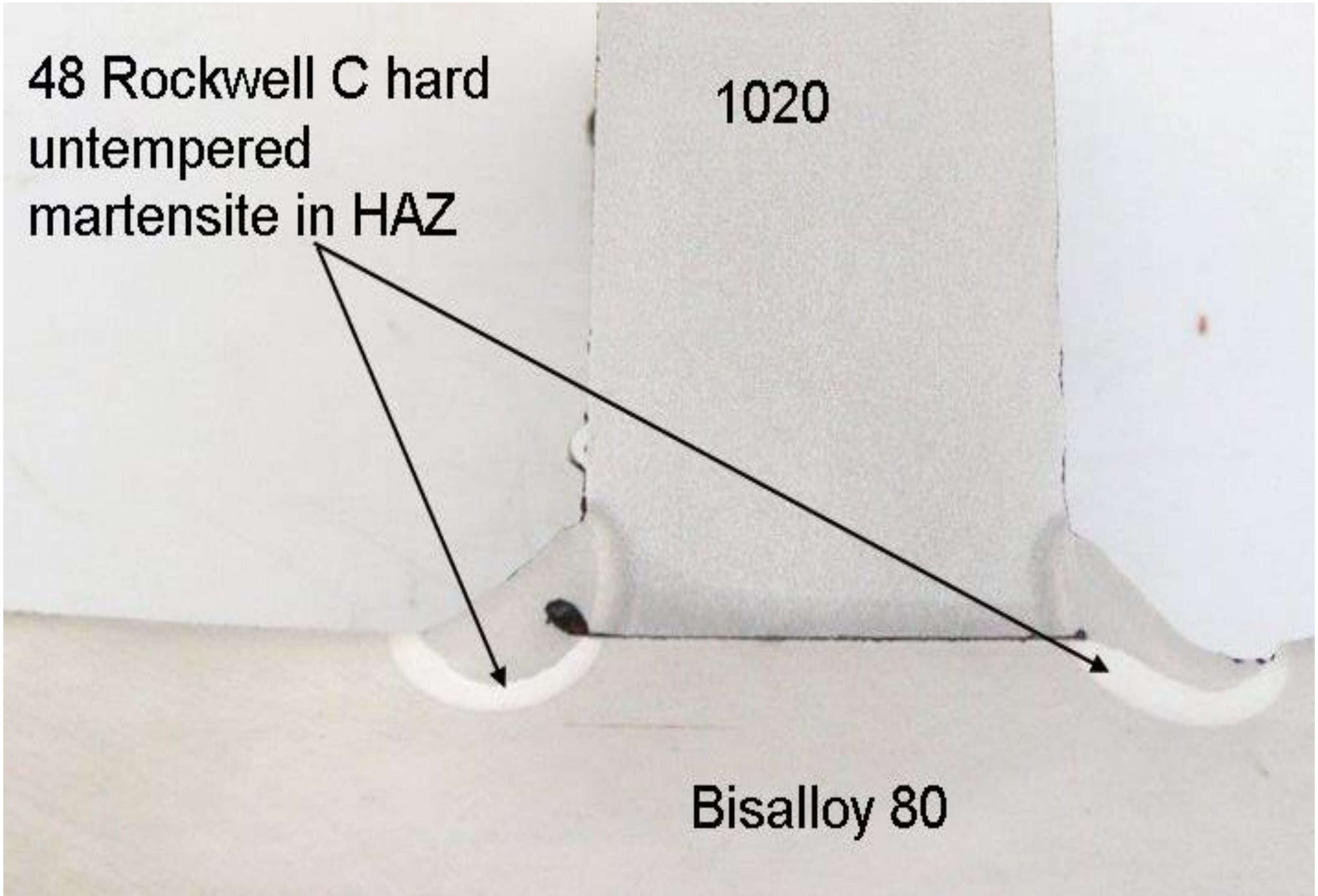
Not only is the weld metal heated, but also the steel immediately next to the molten weld metal (the Heat-Affected Zone or ‘HAZ’). The heat in this zone varies from approx 1400degC downwards.

Take note that we are talking about the Parent material, NOT the weld metal. This is completely independent of type of rod or filler metal used.

A welder is a ***Heat-Treater***

Parent material in the temperature band of 1400degC down to 850degC is chilled (**quenched very fast**) by the cool mass of parent metal and can readily harden to 55 HRc depending on the Carbon Equivalent.

Cool steel quenches hot steel much better than a liquid! This means a welder is much more effective at creating hard brittle martensite in steel than a heat-treater is.


48 Rockwell C hard
untempered
martensite in HAZ
1020
Bisalloy 80

Creation of hard brittle martensite (with associated root cracking) can be **reduced** by <u>high and thorough pre-heat</u>,

but **only a proper post-weld heat-treat (PWHT)** can achieve the ‘big 3’ essentials of:

- ✓ Tempering the martensite, transforming the brittle quenched martensite into desirable, tough Tempered Martensite.
- ✓ Lowering the hardness.
- ✓ Relieving the stresses.

Pre-heat for Welding

Preheating slows the rate at which the parent material draws the heat out of the weld.

A thorough and hot enough preheat will reduce the risk of tiny quench cracks occurring in the HAZ (Heat-Affected Zone)

Preheat must be thorough, and must be maintained for the duration of welding.

Measure the temperature well – and be very careful with infra-red ‘laser point’ devices as they do not measure temperature!

How hard a steel will get in the HAZ (or how much martensite is created) is governed by its **Hardenability**.

Hardenability is measured by **Carbon Equivalent**:

$$CE(IIW) = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Cu + Ni)}{15}$$

Using this simple calculation will quickly give you an idea of whether preheat or PWHT may be required.

The Carbon Equivalent number can be used together with the steel thickness to give you an idea of the level of preheat required in the following table.

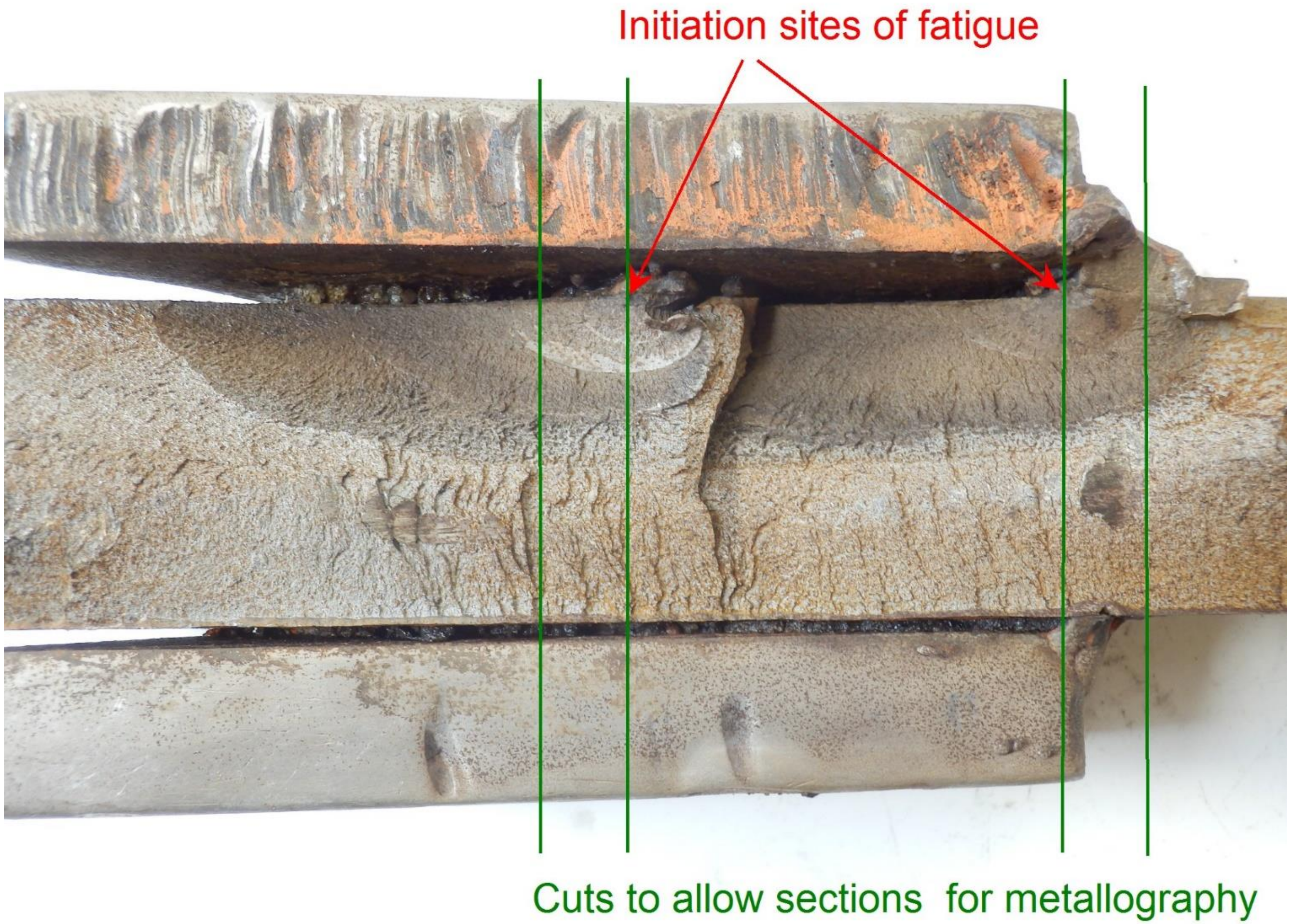
Carbon Equivalent CE (IIW)	Thickness of workpiece				
	20mm	**40mm**	**60mm**	**80mm**	**100mm**
0.3	150	150	150	150	170
0.35	150	150	170	180	190
0.4	180	190	200	210	220
0.5	200	210	220	230	250
0.6	220	240	260	270	280
0.7	250	270	280	300	320
0.8	280	300	320	340	350

Approximate guide for minimum weld preheat temperatures

(Degrees Celsius)

- A high preheat will help prevent hard martensite, and cracking around the weld.
- PWHT will transform hard brittle martensite to tough tempered martensite.
- PWHT will relieve some nasty weld stresses.
- Do not exceed the Temper temperature of the lowest-tempered steel in the job during PWHT!
- Cracked welds have stress-relieved themselves already! ☺

This digger bucket sidewall, fractured when small cracks in the HAZ (Heat-Affected Zone) of the welds grew to be large fatigue cracks that propagated until failure occurred. Root cause = No preheat & No post heat.



This heavy transport axle snapped suddenly. You can clearly see the layer of hard brittle martensite caused by the weld.

Where was the Post Weld Heat Treatment?

This failed shaft material had a high Ceq of 0.55, which means that it is essential that the parts are properly preheated for welding, and fully PWHT (stress-relief / temper) after welding.

The fact that we observe untempered martensite in the HAZ points to either a poor weld procedure, the procedure not being followed, or the shaft being welded without a weld procedure. Just look at these hardness test results…..

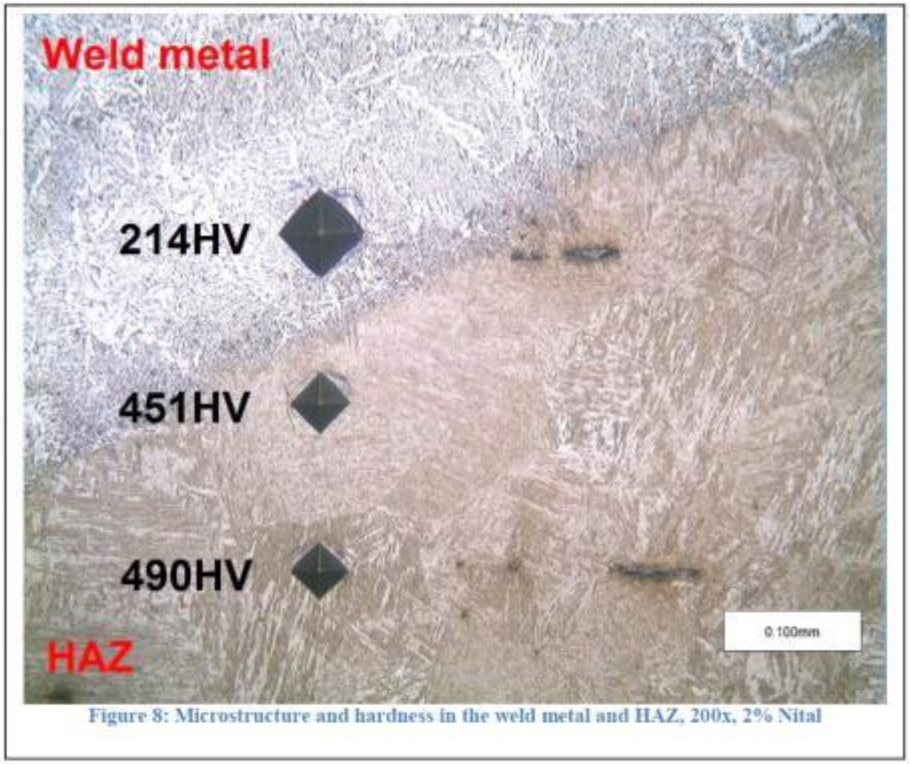
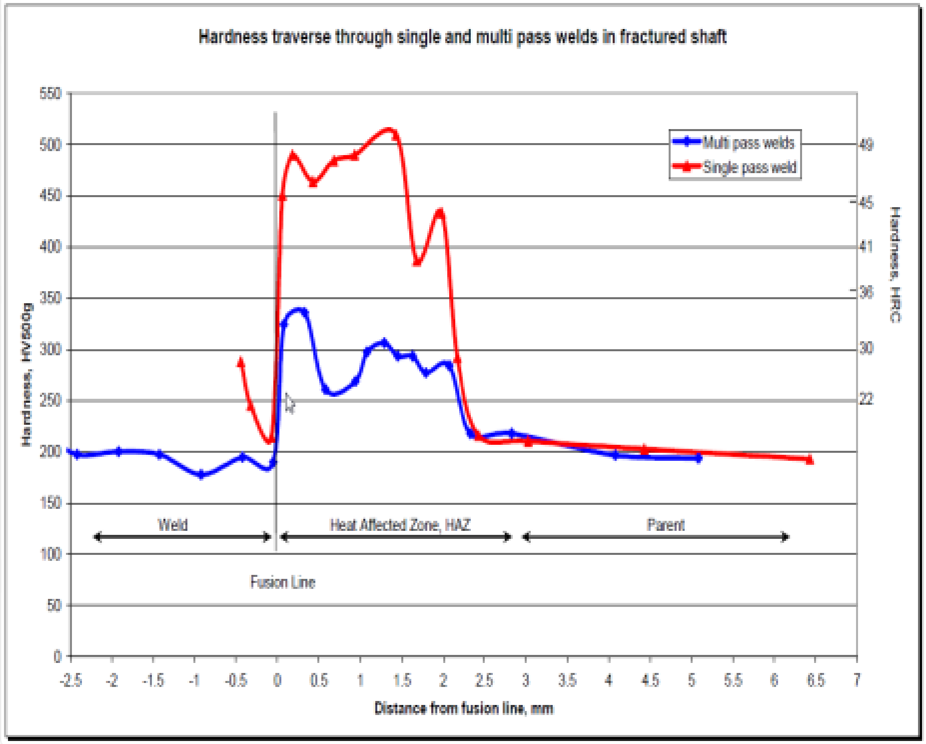


Figure 8: Microstructure and hardness in the weld metal and HAZ, 200x, 2% Nital



A General, best-practice welding guide for hardened Wear Steel & GET Parts.

1. Ensure clean weld surfaces & the correct weld preps
2. Lightly tack the parts in position. Caution*
3. **PREHEAT** the welding area to 150-250degC.
4. Fully weld the parts together with correct wire or rods.
5. When welding is finished, cover the welded area with a welding blanket to allow **SLOW COOLING.**
6. Once cooled, heat the area up again to approx. 30degC lower than the tempering temp of the lowest tempered part, cover with a welding blanket to allow slow cooling again. This is the **POST HEAT** treatment which has now softened the brittle HAZ and hopefully de-stressed your steel & the welds, significantly reducing the risk of failure/cracking.

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