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Ultra High Strength Steels Alloyed with Boron

1. Introduction

Boron is a small **interstitial** element which is added to fully killed and de-oxidised steel to improve **hardenability**.

- **Boron-treated steels** are produced in the range 0.0005 – 0.005% added boron and are most effective in lower carbon steels < 0.40% C.
- **Boron** increases the **strength** of heat-treated steels in the quenched and tempered condition.
- **Boron** can be substituted for other alloying elements, maintaining the **hardenability**.

Boron steel grades can be **hot worked** using cooled tooling by pressing, bending and forging. **Quenching** from hot working temperature; produces a rapid cooling rate and a **martensitic microstructure** which is auto-tempered to produce **high strength, tough, hard, durable and wear resistant components.**

2. Applications

- **An economically attractive alternative to conventional engineering steels with process and production benefits.**
- The combination of good abrasion resistance and high strength, allow innovative freedom of design.
- Fork-arms for materials handling use 0.30% carbon manganese boron steel modified with minor additions of chromium and/or molybdenum.
- Wear components including; ground engaging tools, wear plate, screen plate, punching tools, spades, knives, saw blades and caterpillar tracks
- Structural components including; safety parts in automotive, agricultural machinery.
- Alternative to hot work tool steel H13 and cold work tool steel D2 in fork-arm manufacturing.

3. Steel-making

Boron has a great affinity for oxygen and nitrogen and if allowed to combine the hardenability benefits will be lost.

- Therefore, the steel must be fully de-oxidised and a strong nitride forming element added. **Aluminium is used to reduce the oxygen level and Titanium to reduce the nitrogen level; typically residual levels ~ 0.030%.**
- **Boron steels** can be manufactured with modified inclusions and low inclusion counts to aid formability in the through thickness direction.

4. Hardenability

The minimum level for increased hardenability is 0.0008%, further additions having little additional effect, typical actual results are 0.002 – 0.003% boron in solution.

- Additions of chromium (up to 0.70%), molybdenum (up to 0.5%), vanadium & niobium (trace only) are made to increase depth of hardening and improve temper resistance.
- **The effect on hardenability is greatest during rapid cooling when boron is retained in solution within the grain, locking the martensitic transformation.**

5. Heat Treatment

The **limited solubility of boron** has a dramatic effect on transformation characteristics in heat treatment. Boron retards the formation of ferrite and pearlite, promoting the formation of martensite during rapid cooling and not depressing the martensite start (M_s) temperature.

- **When quenching boron steels, it is important that the cooling rate is high enough to produce a martensitic microstructure; developing higher strength and good toughness.**
- Slow cooling rates will lead to the presence of; upper and lower bainite, widmanstatten ferrite; developing lower strength and poor toughness.

Boron steels are either; fully heat treated by harden, quench and temper or; quenched and auto-tempered from hot working temperature.

6. Hot Working

Boron steels are less susceptible to grain growth due to the presence of titanium and have a wide hot working range. Typically;

- Hot working temperatures ~ 1050^0C
- Quenching temperatures ~ 900^0C.

7. Machinability

In the as rolled / delivered condition **boron steel grades** are softer than equivalent engineering steel grades, avoiding the need for costly annealing operations prior to forming operations.

- The addition of boron does not impair machinability, cutting, punching or drilling
- Suitable for oxy-fuel profiling
- Suitable for cutting by sawing

8. Weldability

Boron steels, in spite of, good hardenability are readily weldable and can be welded in either the as rolled or heat treated condition. Suitable welding processes include but not limited to;

- Manual metal arc with basic electrodes
- All combinations of gas shielded metal arc
- Auto-geneous TIG
- Resistance spot welding
- Laser conduction and/or laser penetration welding
- Friction welding processes

The heat affected zone

- The presence of titanium reduces the grain coarsened region and extends the grain refined zone.
- If, the cooling rate in the grain coarsened region is high, there is a risk of the formation of coarse untempered martensite which is brittle and susceptible to hydrogen cracking.

When welding **boron steels** precautions should include but not limited to;

- Low hydrogen practice
- Calculation of pre-heat using the P_{cm} formula, suitable for micro-alloy and **boron steel grades**.
- Aim to keep pre-heat and interpass temperatures below martensite finish (M_f) temperature.
- Regulate and control heat input to maintain interpass temperature.
- Avoid very high heat inputs; which may lead to heat sink and quenching effects in the heat affected zone.
- Apply post heat below M_f temperature to reduce cooling rate and temper any coarse martensite which may form in the heat affected zone.

For technical support;

- **When changing to boron steel grades.**
- **When using boron steel grades**

For information concerning the sourcing of boron steels through Bimax plc.

- **Boron steels are available in flats, plates and round forms**

For information concerning application of the IntensiQuench[SM] process and equipment in cell manufacturing – forge – quench – auto-temper operations.

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