# WELDING of Cr-Mo STEELS for ENERGETIC INDUSTRY

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**Abstract**

Paper gives an overview and main characteristics of low alloyed steels based on chromium and molybdenum as the main alloying elements. Chrome-moly steels are intended for high temperature applications especially for the need of energetic industry. Welding issues of these steels is presented and general recommendations for welding of CrMo steels are presented. In experimental part of this paper GTA welding of 10 CrMo 9 10 tubes in 5G position were performed in such a ways that approved welding procedure specification (WPS) was, regarding thermal conditions and prerequisites disobeyed, (no preheating and no control of interpass temperatures) without and with tubes restrain and with complete obeying of WPS using restrain. Disobeying adequate welding procedures can result in detrimental quality loss by welding of 10 CrMo 9 10 tubes.

**Keywords:**

**Low alloyed steels, Cr-Mo steels, Weldability, GTA (TIG) Welding, Welding Procedure Specification, Tubes**

## Introduction

Chromium – molybdenum (Chrome–Moly or Cr-Mo abbreviated) group of steels are low alloyed steels with up to 9 % of chromium, 0,5 % to 1 % of molybdenum and typically up to 0,15 % carbon, [1].

Chrome-Moly steels have a structural application and they are often used in energetic sector for pressure vessels, boilers and other parts or elements because they successfully withstand stresses, temperatures up to around 500 °C and moderate corrosion issues.

One of the most prominent prerequisites on chromium – molybdenum steels is that they are weldable. Although weldability of CrMo steels is treated as good they are not immune on certain issues which could arise during welding.

Alloying elements, hardenability and possible difficulties in application of suitable welding procedures in industrial environment or on the construction site can cause lower quality of welded joints.

This paper discusses CrMo steel family and deals with their welding and weldability. Experimental work is performed in order to research how different implementation of welding procedure specifications based on Gas

Tungsten Arc (GTAW) or Tungsten Inert Gas (TIG) welding process of CrMo tubes influence the welding output in simulated workshop welding.

**Chromium – molybdenum steels**

Chromium – molybdenum steels are low alloyed ferritic steels and can retain desired strengths and withstand operating temperatures up to 500 °C or 550 °C (CrMoV). Beside chromium and molybdenum, vanadium and tungsten can further improve the heat resistance of steel at high temperatures. CrMo steels are steels from Group 5 and CrMoV steels are Group 6 according to CEN ISO/TR 15 608.

*Effects of main alloying elements*

Carbon is strengthening element in steel but it impairs capability of successful joining by welding. Carbon content in CrMo steels is low and weldability of that steel family is usually stated or referred as good.

Chromium by alloying strengthens the steel and at the same time has several additional beneficial effects. Due to the formation of oxides it assures corrosion resistance (higher Cr content better corrosion resistance). Chromium enables hardenability by heat treatment. At the same time chromium is very prone to combine with carbon forming thermally very stable and beneficial chromium carbide. Melting point of $Cr_3C_2$ is 1893 °C (3440 F), [2].

Molybdenum hardens steel and form carbides. Molybdenum's especially beneficial role is that it preserves the strength of steel at high temperatures, ***figure 1***, and in that way is helpful in reducing the creep effects, [3]. Molybdenum carbide ($Mo_2C$) is thermally extremely stable because its melting point is very high (2413 °C ie 4375 F), [2].

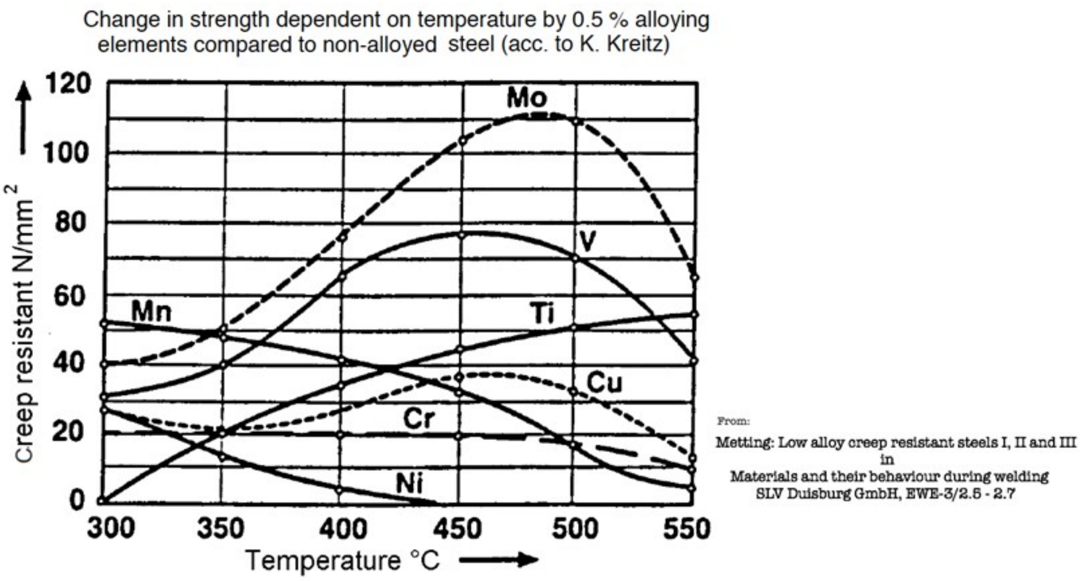



***Figure 1 –Effect of various alloying elements in steel on creep resistance, [3]***

Synergistic effect of increased chromium and molybdenum contents in steels ensure elevated temperature strength along with oxidation and sulfide corrosion resistance. Both of these alloying elements improves resistance to hydrogen attack and creep, [1]. Generally, Cr, Mo and V carbides are thermally more stable and more resistant to coagulation at high temperatures than iron carbide. If carbides are in the microstructure dispersed evenly and as a very fine precipitates they suppress or resist creep.

Mechanism of plastic deformation and metal failure at elevated or high temperatures under constant and long lasting stress which is lower than yield or proof 0,2 point is known as creep. It is usual that exposure of metallic materials that takes $10^5$ hours and more are defined as long lasting stresses. Creep rupture strength or creep limit are measured by suitable tests at specified temperature important for service. Typical design lifetime is usually 100 000 hours.

Creep failures are frequently observed at welded joints and at locations of stress concentration. Weldments in this sense could be treated as critical points because they are susceptible to surface, subsurface or volumetric discontinuities. Beside that, welded joints exhibit different microstructural phases or grain sizes and shapes and are usually additionally loaded by residual stresses. Cracks, incomplete fusion, partial penetration or elongated slag inclusions are sharp linear indications and high stressors. Discontinuities like porosities, short slag inclusions and heavy metal inclusions can be considered as rounded (circular, elliptical, irregular rounded) and as such are not so dangerous stressors.

One of the most frequently used steels from CrMo family is 21/4Cr1Mo according to ASME designations or according to European norms. Typical and standardized chemical composition of 10 CrMo 9 10 according to German and Euro norms is given in ***table 1***, [4].

***Table 1 – Minimal and maximal percentage mass content of elements in chemical composition of 10 CrMo 9 10 steel, [4]***

| C | Cr | Mo | Mn | Si | P | S |
|---|---|---|---|---|---|---|
| 0,15 | 2,0 – 2,5 | 0,9 – 1,1 | 0,4 – 0,6 | 0,5 | 0,04 | 0,04 |

Continuous cooling diagram (CCT) for 10 CrMo 9 10 steel is presented in ***figure 2***.

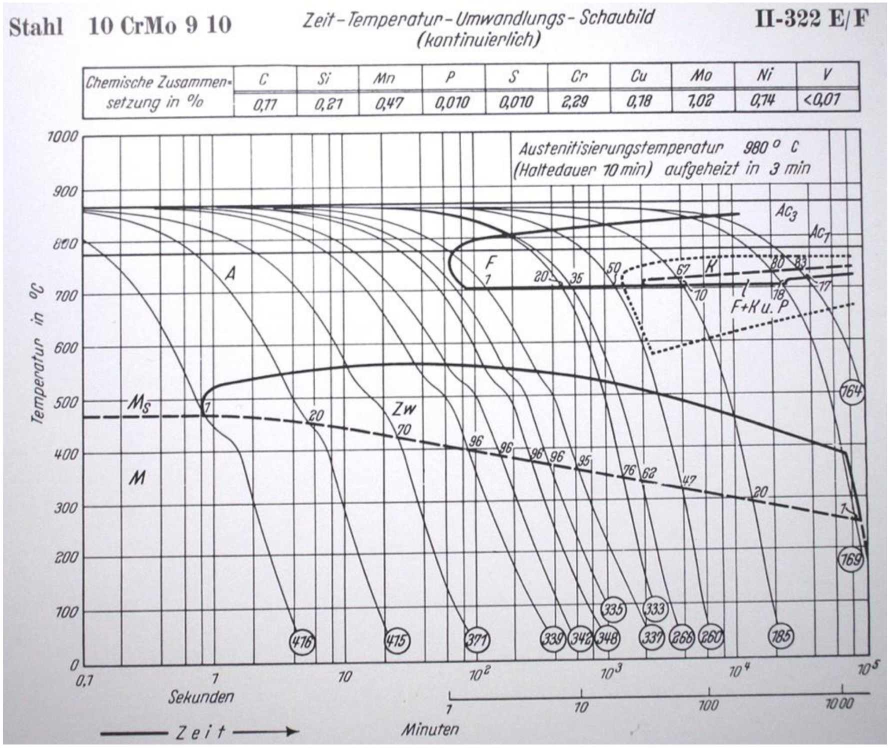
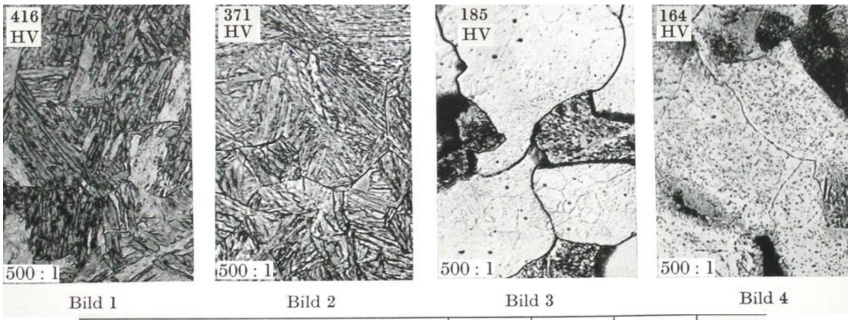



***Figure 2 – CCT diagram of 10 CrMo 9 10 steel, [4]***

Chromium-molybdenum steel 10CrMo9-10 is usually delivered in two conditions, both requiring suitable heat treatments. In one case 10CrMo9-10 is normalized and subsequent tempered (NT) or it is quenched and then tempered (QT). Normalization or quenching and subsequent adequate tempering ensures to CrMo steels homogeneous microstructure with evenly distributed carbides. These alloys can also be heat treated as full annealed, isothermal annealed and normalized.

Critical cooling time between 800 °C and 500 °C for obtaining only martensite in 10CrMo9-10 is extremely short, it is less than 1 second. Product of such a cooling rate is martensite (99 % and 1 % of bainite) with hardness of 416 HV, left microstructure in ***figure 3***.




| | | Bild 1 | Bild 2 | Bild 3 | Bild 4 |
|---|---|---|---|---|---|
| Ferrit | in % | — | — | — | — |
| Ferrit mit Karbidausscheidungen | in % | — | — | 67 | 83 |
| Eutektoid F + K | in % | — | — | 10 | 17 |
| Perlit | in % | — | — | | |
| Zwischenstufengefüge | in % | 1 | 70 | 20 | — |
| Martensit | in % | 99 | 30 | 3 | — |

***Figure 3 – Microstructures and obtained hardness on samples of 10 CrMo 9 10 steel obtained by various cooling rates, [4]***

Faster cooling rate and cooling time between 800 °C and 500 °C which is app. 15 s results in bainitic/martensitic structure with prevailing bainite (70 %), second micrograph from left in ***figure 3***.

Very slow cooling rates which are obtainable by heat treatment but is not realistic in welding situations, result mostly in ferrite with embedded and finely dispersed carbide precipitates microstructure accompanied by eutectoid (third micrograph from left in ***figure 3***, cooling time between 800 °C and 500 °C over 2 hour app.) and bainite (fourth micrograph from left in ***figure 3***, cooling time between 800 °C and 500 °C over 20 hours).

Even for relatively slow cooling rate by welding it is to expect bainitic/martensitic structure as it is established for welding needs by welding continuous cooling diagrams (CCT), ***figure 4***, [5]. For example, for cooling time between 800 °C and 500 °C which is more than 3 minutes there will be more than 90 % bainite and rest is martensite. For obtaining the microstructure after welding which has a hardness slightly over 300 HV (317 HV) it is necessary to cool from 800 °C to 500 °C in more than a 60 seconds.

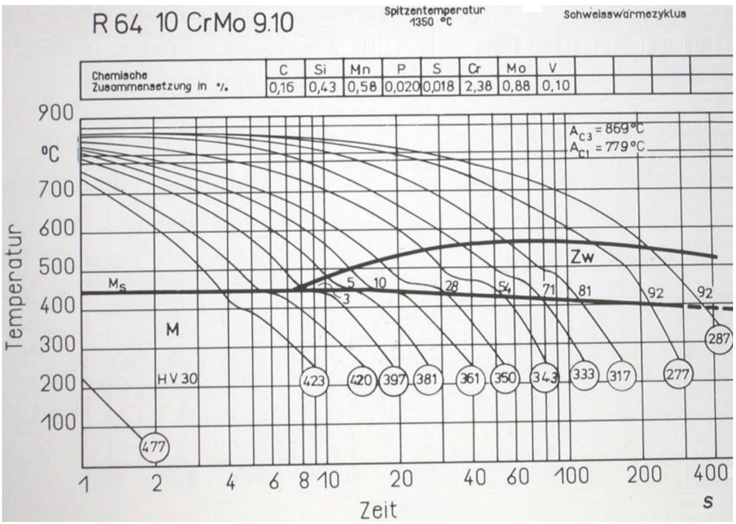



***Figure 4 – CCT welding diagram for 10 CrMo 9 10, [5]***

Different microstructures as a result of various cooling rates from temperature which corresponds to the coarse grain zone are presented in ***figure 5***.

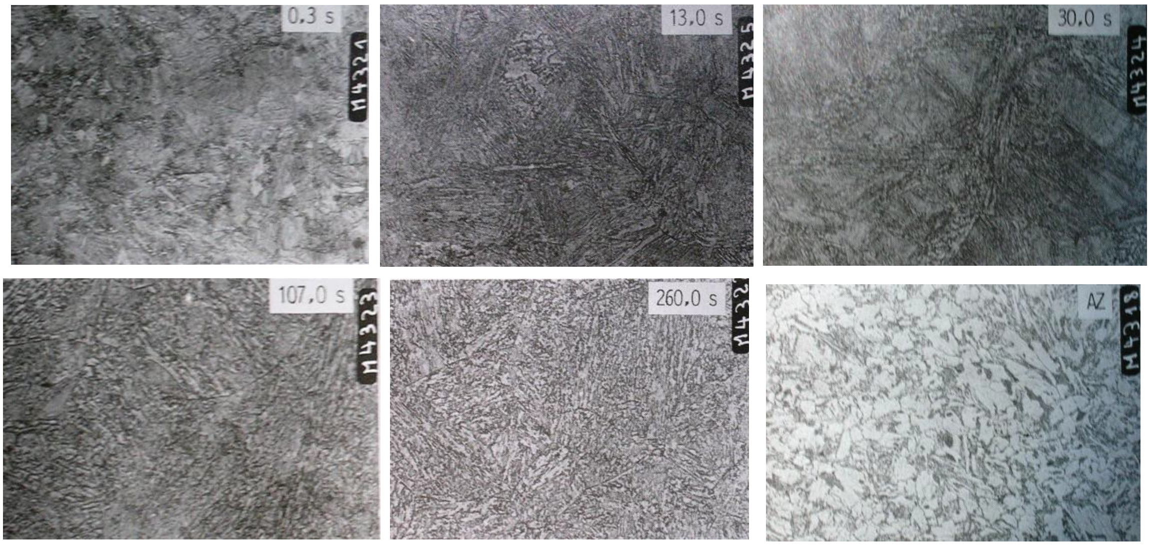



*Figure 5 – Different microstructures obtained by different continuous cooling rates from 1350 °C for 10 CrMo 9 10, [5]*

**Application of CrMo Steels for Energetic Sector**

Chrome-moly steels are according to international, American and European norms specified as flat semiproducts, seamless tubes/pipes, welded tubes/pipes, forgings, castings, bars, fasteners …

Pressure vessels and boilers are structures which usually work in aggressive surroundings at higher temperatures and under have corrosion issues. It was established that in having CrMo steels with high chromium contents for high-temperature steam applications do not significantly improve corrosion resistance compared to steels with 2,25 %.Cr.

**Welding of CrMo Steels**

Due to the specific microstructure of CrMo steels which is thermally sensitive welding processes can change or negatively influence their structure and as a consequence mechanical and chemical properties.

Most of the traditional and modern welding processes can be applied for welding CrMo steels but usually electric arc processes are those which are worldwide accepted and in broad industrial application - shielded metal arc welding (SMAW), submerged arc welding (SAW) and gas tungsten arc (GTAW) or tungsten inert gas welding (TIG), gas metal arc welding (GMAW) and flux cored arc welding (FCAW). Among those processes two of them are, according to the metal thickness, shape and welding position, most frequently used – SMAW and GTAW.

During arc welding, part of the base metal is heated above critical temperatures and owing to the hardenability of the CrMo steels can be hardened to the unacceptable levels (higher than base metal). Similar situation can be realized in weld metal so it is necessary to take care about and control the integral thermal cycle during welding in order to prevent quenching. In multipass welding the heat flow is very dynamic and changeable resulting in complex temperature cycles.

According to that, workpiece should be prior to any arc operation preheated to the suitable temperature. Preheating is mandatory for both, tack welding and welding. Interpass temperature as measured on the base metal adjacent to the welded joint is to be strictly controlled and maintained during the whole welding. Cooling phase after welding have to be controlled to. Finally if it is necessary post weld heat treatment (PWHT) is to be undertaken. Generally, PWHT understands welded joint's heating and controlled cooling (usually slow) immediately after welding in order to temper, stress relieve or to obtain favourable microstructure.

Preheat temperatures are dependable upon steel chemical composition and thickness and can be found in literature. It is to take care about hydrogen levels by welding od CrMo steels and to minimize sources of hydrogen in base and filler metal as well as in the shielding gas.

Filler metals for this steels are from the same group and it is similar to the base metal in respect of chemical composition and obtainable properties. Covered electrodes have to be dried before welding.

For 10CrMo9-10 recommended filler metal for GTAW is designated CrMo2 and recommended preheating and interpass temperatures are in the range from 200 °C to 300 °C. If PWHT is necessary for 10CrMo9-10 than it is recommended to be in the temperature interval from 650 °C to 700 °C or max. at 750 °C. Recommended minimum holding times of 15 min, 30 min and 60 min for thicknesses up to 15 mm, between 15 mm and 30 mm and for over 30 mm respectively are to be found in specifications, [6]. With stress relieving heat treatment one has to be very cautious because if treated too long it can create degradation of thermal properties.

As the consequence of inadequate welding procedures or because of welder incompetence various defects in CrMo weldments can be encountered. Due to the CrMo steels hardenability in cases of restrained welded joints and hydrogen cold cracks can arise, ***figure 6***.

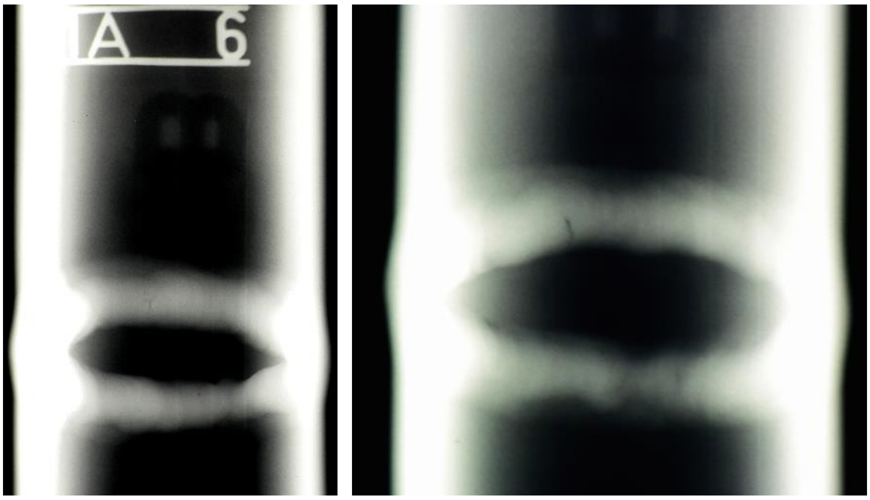



***Figure 6 – Radiograms with transversal crack and crack in crater of the welded joints in 10 CrMo 9 10 tubes, [7]***

**Experimental**

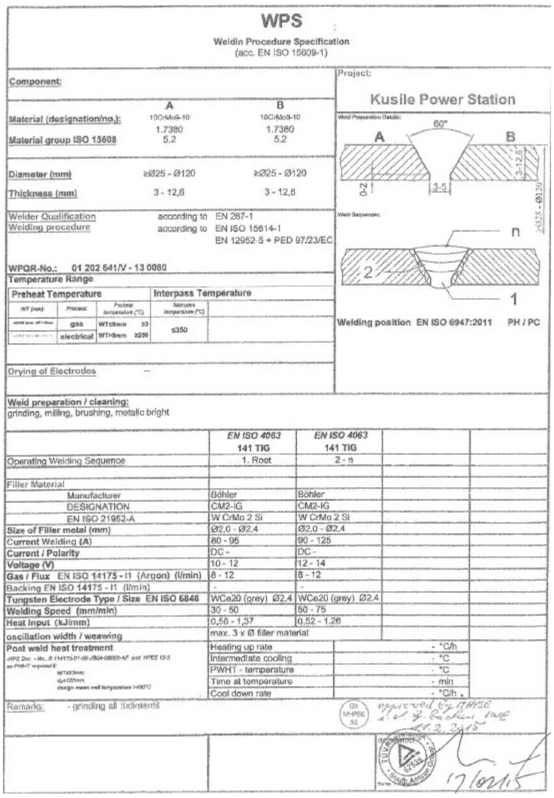
In order to establish how different approach to execution or implementation of a welding procedure specification affect the welding quality output of CrMo steel three mockup welded joints on the CrMo tube were realized. Welding was based on the proven welding procedure specification (WPS), ***figure 7***.

Seamless tube with outer diameter of 68 mm and wall thickness of 12 mm made of 10 CrMo 9 10 in NT condition was used as the base metal. Tube was welded in multipass technique by GTA welding process using CrMo2 filler metal of 2,4 mm in diameter. Direct current and cathode on the tungsten electrode 2,4 mm along with argon as a shielding gas was applied. Welding position was 5G.

Tubes were preheated by diffuse flame and temperatures were checked by IR thermometer and by thermo crayon in the range of 70 mm from both sides of the joint.

As the production welding conditions can vary significantly and as the welders may disobey or disregard WPS following simulated workshop welding, ***figure 8***, was performed:

A. tube welded in 5G position according to the approved WPS but without preheating and without restrain,
B. tube welded in 5G position according to the approved WPS without preheating, at the end of every layer was forced cooled and restrained and
C. tube welded in 5G position according to the approved WPS and restrained.



**WPS**

Weldin Procedure Specification
(acc. EN ISO 15609-1)

Component:

Project: Kusile Power Station

| | A | B |
|---|---|---|
| Material (designation/no.): | 10CrMo9-10 1.7380 | 10CrMo9-10 1.7380 |
| Material group ISO 15608 | 5.2 | 5.2 |
| Diameter (mm) | ≥Ø25 - Ø120 | ≥Ø25 - Ø120 |
| Thickness (mm) | 3 - 12,6 | 3 - 12,6 |

Welder Qualification according to EN 287-1
Welding procedure according to EN ISO 15614-1
EN 12952-5 + PED 97/23/EC

WPQR-No.: 01 202 641/V - 13 0080

Weld Preparation Details:



Weld Sequence:



Welding position EN ISO 6947:2011 PH / PC

Temperature Range

| Preheat Temperature | | | Interpass Temperature |
|---|---|---|---|
| WT (mm) | Process | Preheat temperature (°C) | Interpass temperature (°C) |
| | gas | WT≤8mm ≥5 | ≤350 |
| | electrical | WT>8mm ≥200 | |

Drying of Electrodes --

Weld preparation / cleaning:
grinding, milling, brushing, metallic bright

| | EN ISO 4063 141 TIG | EN ISO 4063 141 TIG |
|---|---|---|
| Operating Welding Sequence | 1. Root | 2 - n |
| Filler Material | | |
| Manufacturer | Böhler | Böhler |
| DESIGNATION | CM2-IG | CM2-IG |
| EN ISO 21952-A | W CrMo 2 Si | W CrMo 2 Si |
| Size of Filler metal (mm) | Ø2,0 - Ø2,4 | Ø2,0 - Ø2,4 |
| Current Welding (A) | 80 - 95 | 90 - 125 |
| Current / Polarity | DC - | DC - |
| Voltage (V) | 10 - 12 | 12 - 14 |
| Gas / Flux EN ISO 14175 - I1 (Argon) (l/min) | 8 - 12 | 8 - 12 |
| Backing EN ISO 14175 - I1 (l/min) | - | - |
| Tungsten Electrode Type / Size EN ISO 6848 | WCe20 (grey) Ø2,4 | WCe20 (grey) Ø2,4 |
| Welding Speed (mm/min) | 30 - 50 | 50 - 75 |
| Heat Input (kJ/mm) | 0,56 - 1,37 | 0,52 - 1,26 |
| oscillation width / weawing | max. 3 x Ø filler material | |

| Post weld heat treatment | | |
|---|---|---|
| | Heating up rate | - °C/h |
| | Intermediate cooling | - °C |
| | PWHT - temperature | - °C |
| | Time at temperature | - min |
| | Cool down rate | - °C/h |

Remarks: - grinding all indications

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17.2.2015

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*Figure 7 – Approved welding procedure specification for welding of 10 CrMo 9 10, [7]*

In two cases tubes was restrained by welding their endings on the welding table in order to mimic the highly restrained conditions on the work site in the real structure, ***figure 8***.

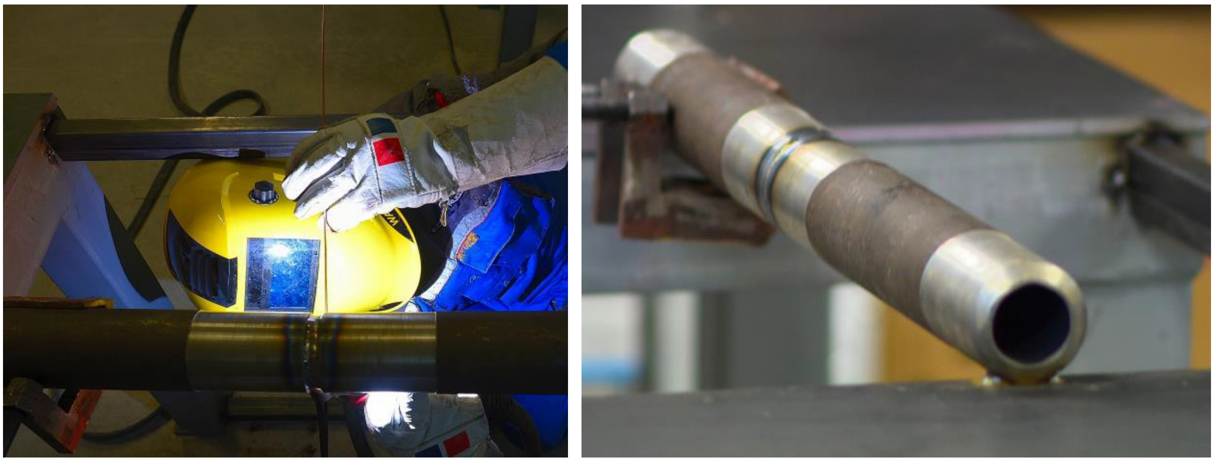

*Figure 8 – GTAW welding of 10 CrMo 9 10 tube and method of tube restraining for B and C cases*

Heat input was between app. 1,4 kJ/mm up to the app. 18 kJ/mm according to the layer and welding location (diameter). Welded joints were finshed in four or five layers and with 8 to 9 beads ie passes.

Without preheating incidence of root discontinuities was more frequent (case A and B). When tube was restrained and without preheating tack welds and even root pass occasionally cracked (case B). in this case cracks was found by penetrant testing on the final pass, ***figure 9***.

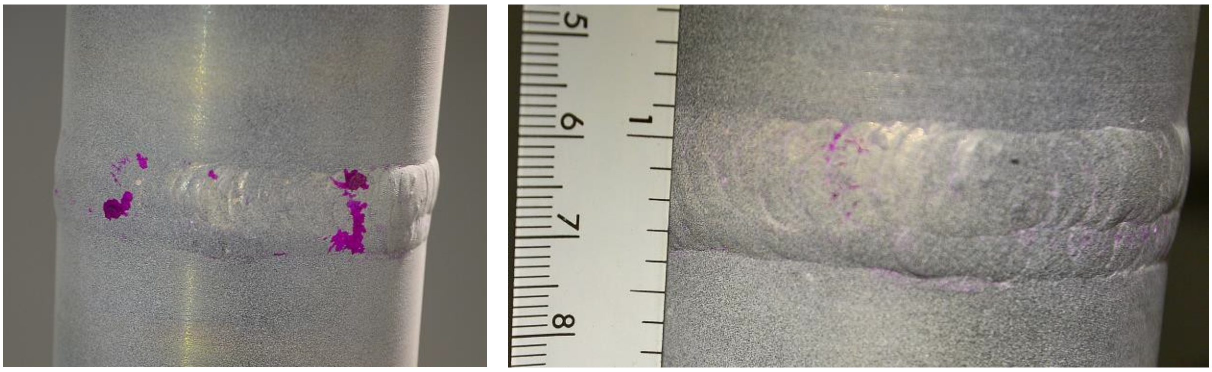

*Figure 9 – Linear and rounded indications as revealed by penetration testing (PT) on the GTAW welded tube of 10 CrMo 9 10 - case B – restrained, without preheat and at the end of every layer forced cooled*

Completely obeying the WPS although the tube was restrained resulted in, after visual, penetration testing (PT) and mechanical sectioning no quality degradation was to establish, ***figure 10***.

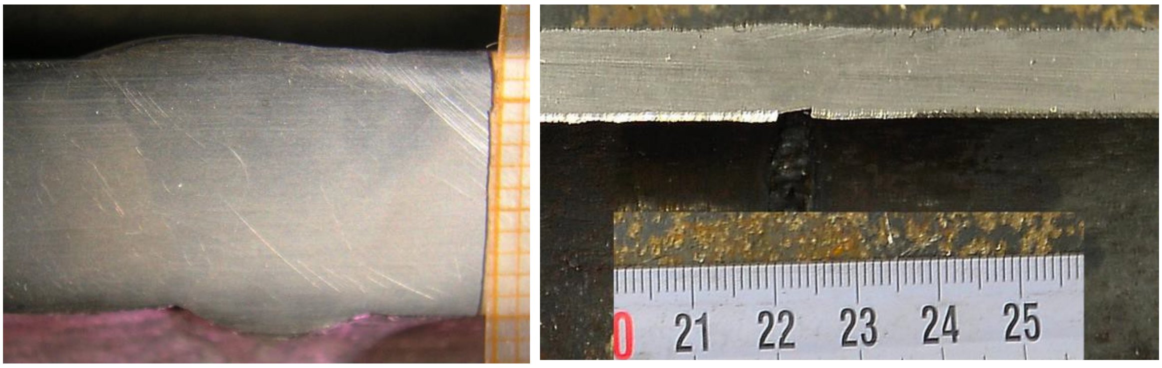


*Figure 10 – Comparison of two cross sections of GTAW welded tubes of 10 CrMo 9 10 according to different conditions and schemes good weldment (case C – left) vs. root discontinuity (case A – right)*

**Conclusions**

Following conclusion can be drawn:

- CrMo steels are low alloyed steel suitable for high temperature applications in energetic sector,
- this group of steels is sensitive to the thermal treatment and by welding they need strict technological discipline,
- failing to preheat restrained 10 CrMo 9 10 tubes during GTAW can result in cold cracks and
- it would be recommendable that preheat and interpass temperature as well as other welding parameters should be checked on test assemblies that are very similar to the actual production and real welding situations.

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