International Journal of Engineering Research and Technology.
ISSN 0974-3154 Volume 6, Number 6 (2013), pp. 767-772

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Properties and Welding Procedure for Grade 91 Alloy Steel

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Abstract

New Martensitic Alloy Steel Grade 91 (9Cr-1Mo-V enhanced) was studied and detected to have exceptionally high creep strength. It was found to have a complex microstructure which was extremely vulnerable to convert into Austenite form near the temperature for heat treatment. The variation in the properties of Grade 91 and Grade 22 alloy steel (presently used for boiler pipes and fittings) was studied. Differing properties on using various methods of welding were noticed, especially GTAW, SMAW and SAW. Final conclusion was drawn to justify the correct procedure for welding of 9Cr-1Mo-V Alloy steel.

Keyword: Creep strength, austenite, martensite, alloy steel, microstructure.

1. Introduction

In this era of energy, there is need of material which enables us to generate maximum power. Hence, the experiments on new alloys are being conducted. Alloy Steel provides good creep strength and can be used to generate power in high pressure boilers where temperatures are extreme. Amongst these, Grade 91 is specially modified 9% Chromium, 1% Molybdenum, Vanadium enhanced (9Cr-1MoV). Development of 9Cr-1MoV began in 1978 by Oak Ridge National Labs for breeder reactor and has been further developed by other researchers since then.[1]It was used in Germany in large scale from 1990 onwards. Generally used for Superheater sections in boilers. Superheaters are prone to more creep damage because of high temperature at which they operate.

2. Experimental

2.1 Material

The properties of Grade 91 wholly depend on its chemical composition and microstructure. As per the chemical composition the minimum Carbon content is to be 0.08%, minimum Niobium content is to be 0.03% and minimum Nitrogen of 0.02% is specified to ensure adequate creep strength. It requires 9% Chromium, 1% Molybdenum and minimum 0.18% Vanadium with 0.3-0.6% Manganese, 0.02% Phosphorous maximum, 0.01% Sulfur maximum and 0.2-0.5% Silicon. Niobium level can be taken slightly lower if Titanium is added.[3] Titanium is an effective substitute for niobium, but its level should not exceed 0.010%. This is because of tendency of titanium to combine with nitrogen. This reduces the efficiency of nitrogen to act as creep strength enhancer.

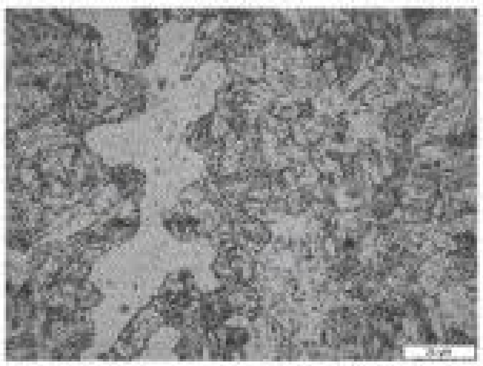

Fig. 1: Microstructure of Grade 91 Alloy Steel [4].This photograph appears courtesy of[B. ShashankDutt]

2.2 Welding Electrode

There are norms to ensure correct welding procedure. Alloy Steel Grade 91 can be welded using methods such as GMAW, GTAW, SAW and FCAW. The most important thing is electrode used for welding Grade 91. The electrode preferred for welding this material is E-9015-B9-H4. This welding electrode consists of 0.08-0.13% C, 1.25% Mn, 0.3% Si, 0.01% P and S each, 1% Ni, 8-10.5% Cr and 0.85-1.2% Mo.[5] It requires DCEP type of current. Additional elements present in small amounts are V, Cu, Al, Nb, and N.

Another important thing to notice is the presence of Hydrogen. Grade 91 is easily hardened, hence it produces hydrogen cracks. Thus, it must be ensured that the level of hydrogen is minimum.E-9015-B9-H4 has very low hydrogen; and hence is best suited for welding of such a critical metal.

2.3 Welding Procedure

Welding of such material is done at elevated temperature. The preheat temperature and Interpass temperature is kept in the range of 400-550^{o}F. Under these mentioned conditions, the welding was done. For welding,a wide, flat bead is considered best suited. Thus, a slight weave technique with high travel speed is specified. After the welding, the material is kept at elevated temperature to keep it dry before Post Weld Heat Treatment (PWHT). Die Penetration Test was conducted to check for any flaw in the welding. This was done to protect the material from the action of contaminants especially Hydrogen. During welding Heat Affected Zones (HAZ) occur and they are handled very carefully. These are the soft spots on the material and most prone to breakage or rupture.

2.4 Post Weld Heat Treatment

PWHT is required for Grade 91 sheets. Grade P91 (Seamless Pipe of grade 91; SA-335[3]) is to be normalized at 1900^{o}F [1040^{o}C] minimum and then tempered at 1350^{o}F [730^{o}C] minimum as a final heat treatment. Alternatively, liquid quenching and tempering is allowed for thicknesses above 3 in. The temperature was taken to 710^{o}C with heating rate of 100^{o}C per hour and was held for 10 hrs. The metal reached in red hot phase. Then the material is allowed to cool down in air.

3. Results and Discussion

PWHT plays a vital role determining the strength of the alloy steel. Even after welding and during PWHT, the microstructure of material can be destroyed. If this happens, then the material loses all its creep strength at once. In worst conditions, it may even have lower creep rupture strength as compared to Grade 22.

If the complete procedure is carried out successfully, then the material shows higher creep strength as compared to generally used alloy steel. Though, different welding methods exhibit different mechanical properties. Mechanicalproperties of Filler metals for P91 are given as in table:[7]

Table1: Table comparing mechanical properties in various processes and the filler metal used.

Process	Filler Metal	Deformation (mm)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
SMAW	E9015-B9	3.2	620	730	19.5
GTAW	ER90S-B9	2.5	670	770	19.7
SAW	ER90S-B9	3.0	580	740	20.1

The weld hardness should be in the range of 200-275 Brinell or maximum upto 300 Brinell. But, hardness above 300 Brinell indicates insufficient PWHT and hardness below 175 Brinell indicates overheating of the joint.

If by any chance, the material gets transformed into austenite form, then it is not possible to restore the normalized and tempered microstructure through localized heating. In that case, the affected weld joint is cut out and replaced including a minimum of 2-3 inches of base metal on all sides surrounding the affected joint. Alternate solution is to normalize and temper the entire assembly.

In some cases, cracks occur in the fine grained section of the heat affected zone of a weldment. This happens if the welding process is not followed as recommended. [6]

Fig. 2: Stress Corrosion Cracking in P91 [2].

These are Stress Corrosion Cracks (SCC) occurring in as-welded state of material. The cause of SCC is not identified yet. They may not happen for days after the material has cooled down to ambient temperature. But, they certainly occur. Though, the action of contaminants, such as moisture, after welding and before PWHT might be a probable reason. If the material is kept dry in that period, there are great chances in reduction of SCC. Also, if there are any signs of SCC after welding and before PWHT, then it can be checked using Liquid Penetration Test or Magnetic-Particle Testing before PWHT.

In summary, below is the graph showing the complete process at a glance:

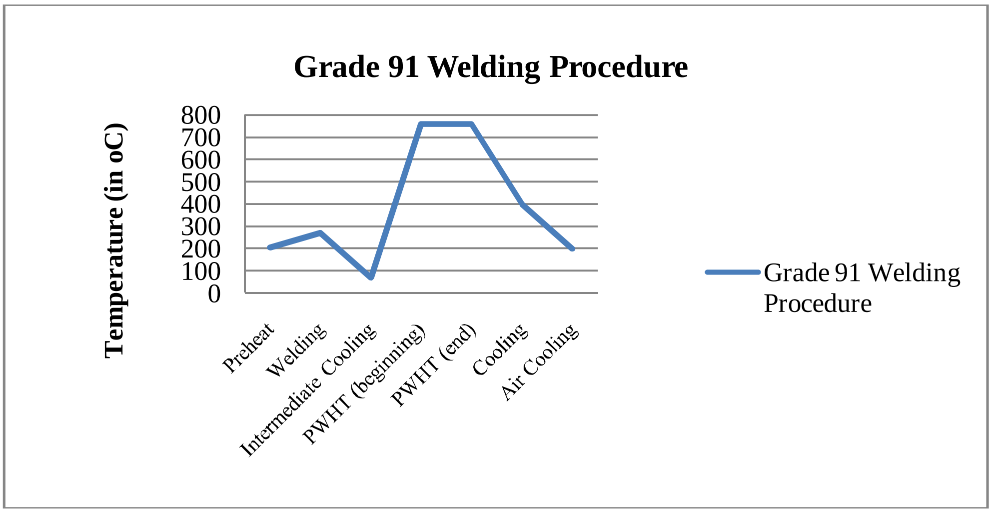

Fig. 3: Welding of Grade 91 seamless pipe (P91) summarized at a glance.

4. Conclusion

Grade 91 Alloy Steel is a complex material to work upon. The most important and difficult task is to maintain its unique microstructure. If not done as per the specified guidelines given in the codes, the material properties can be ruined permanently. The conditions of failure and the methods to prevent them must be followed in order to ensure safe and successful hot working on the material without disturbing its microstructure. Grade 91 is an upgrade to the regular Grade 22 alloy steel. In comparison with grade 22 alloy steel, following observations are made: [2]

1. Reduction in wall thickness by two third; reduction in weight by 60%.
2. Increase in allowable strength in 950-1100^{o}F range by 150%.
3. Increase in oxidation limit by 100^{o}F, enabling lower corrosion allowance.
4. Increase in thermal fatigue life by a factor of 10-12.

References

[1] Welding “Grade 91” Alloy Steel, Sperko engineering Services, http://www.sperkoengineering.com/html/Grade%2091%20R%2010-05.pdf, 2005

[2] Growing experience with P91/T91 forcing essential code changes, Henry Jeffrey F, Alstom Power Inc and ASME Task group, Industry Alert, Combined Cycle Journal, 2005

[3] ASME Section IIA Ferrous Material Specification, ASME, 2004

[4] Dutt B. Shashank, Babu M. Nani, Shanthi G., Venugopal S., Sasikala G., Bhaduri A.K., “Influence of microstructural inhomogeneities on the fracture toughness of modified 9Cr–1Mo steel at 298–823 K”, http://www.sciencedirect.com/science/article/pii/S0022311511009901

[5] ASME Section IIC, Specifications for Welding rods, Electrodes and Filler Metals, 2004

[6] Recommended Practice for local heating of welds in piping and tubing, AWS D10.10, AWS

[7] Welding Filler Metals for power plant engineering, T-PUT, Bohler Welding Group Brochure.