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CONTROL OF CRACKS IN 9CR-1MOV (P91) MATERIAL

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1. INTRODUCTION

Alloy Steel provides good creep strength and can be used in extreme temperature conditions. Amongst these, Grade 91(also known as P91) is specially modified 9% Chromium, 1% Molybdenum, Vanadium enhanced (9Cr-1MoV). Development of 9Cr-1MoV began back in 1978 by Oak Ridge National Labs for breeder reactor and has been further developed by other researchers since then. The pipes we welded were meant for high temperature and high pressure services. Since P91 is modified with vanadium, nickel, aluminum, niobium and nitrogen, it develops very high hardness. Tramp residual elements in this steel, such as phosphorous, sulfur, lead, tin, copper, antimony and other elements will segregate to the grain boundaries during solidification of the weld, and, since the weld metal is very hard, it will crack quite easily. It is, therefore, very important to use low residual filler metal and give great care during welding.

Several types of discontinuities may occur in welds or heat affected zones. Welds may contain porosity, slag inclusions, lack of inter run fusion and cracks. Of the four, cracks are far more detrimental. Cracks are never acceptable. Cracks in a weld, or in the vicinity of a weld, indicate that one or more problems exist that must be addressed. A careful analysis of crack characteristics will make it possible to determine the cause and take appropriate corrective measures. Cracks may be result of solidification, cooling, induced hydrogen and the stresses that develop due to shrinkage. Weld cracks occurs close to the time of fabrication. Hot cracks are those that occur at elevated temperatures and are usually solidification and weld distortion related. Cold cracks are those that occur after weld metal has cooled to room temperature and may be hydrogen related.

Most forms of cracks result from the shrinkage strains that occur as the weld metal cools. If contraction is restricted, the strains will induce residual stresses that causes cracking. There are two opposing forces: the stresses induced by shrinkage of metal, and the surrounding rigidity of base material. The shrinkage stresses increase as the volume of shrinking metal increases. Large weld sizes and deep penetrating welding procedures increase shrinkage strains. The stresses induced by these strains will increase when higher strength filler metals and base metals are involved. With higher yield strength, higher residual stresses will be present. Under conditions of high restraint, extra precautions must be used utilized to overcome cracking tendencies. It is essential to pay careful attention to welding sequence, preheat, inter pass temperatures, post weld heat treatment, joint design, welding procedures and filler material. We are discussing about longitudinal crack that occurred particularly in the P91 material and its control methods.

2. EXPERIMENTAL DETAILS

2.1 Case Study

Welding of P91 material is a tedious task. Welding P91 material generally requires pre heating in the joint, maintaining inter pass temperature, hydrogen bakes and post weld heat treatment. If material cools below minimum pre heat temperature between passes, restraint issues may arise or hydrogen may contaminate the weld. Hydrogen embrittlement can lead to cold cracking of the finished weld.

P91 pipes and elbows were used in this case study. The pipes and elbows were having a diameter of 42 inches (1067mm) and thickness of 52.07 mm were used. Two Welding process were used to complete the welding. GTAW (Gas Tungsten Arc Welding) was used for root and hot pass, whereas SAW (Submerged Arc Welding) was used for fill up and capping. The SAW process depicted cracks and that too in the surface, which was confirmed in NDT activities such as MPT (Magnetic Particle Testing) and UT (Ultrasonic Testing), on the contrary GTAW process was found free of cracks. However, in GTAW process crater cracks may occur due to improper filler wire or lack of welding skill which can be controlled by proper supervision.

The Cracks were found in many joints, so we started various methods to control the cracks considering the metallurgy and various other relevant factors. We would like to share the most effective control method for cracks.

Fig 1: Cracks appeared throughout the SAW weld

2.2 MATERIAL

The properties of Grade 91 wholly depend on its chemical composition and microstructure. According to ASTM and ASME the material composition of ASTM A335/ASME SA 335 P91 shall be

Table 1: Material Composition

C, %	Mn, %	P, %	S, %	Si, %	Cr, %	Mo, %	V, %	N, %	Ni, %	Al, %	Nb, %
0.08-0.12	0.3-0.6	0.02 Max	0.01 Max	0.2-0.5	8-9.5	0.85-1.05	0.18-0.25	0.03-0.07	0.4 Max	0.04 Max	0.06-0.10

The minimum Nitrogen of 0.02% is specified to ensure adequate creep strength. Niobium level can be taken slightly lower if Titanium is added, which 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.

In this particular experiment a pipe and an elbow were welded, whose material compositions are given below along with the weld metal.

Table 2: Material composition of the test specimen

Elements (%)	C	Mn	Si	S	P	Cr	Ni	Mo	Al	V	Nb	N	Fe
Pipe	0.12	0.60	0.50	0.01	0.015	8.79	0.08	0.88	0.006	0.20	0.07	0.032	Bal
Elbow	0.095	0.48	0.256	0.003	0.01	8.58	0.04	0.96	0.007	0.21	0.06	0.041	Bal
SAW Weld Metal	0.1	0.43	0.224	0.006	0.017	8.89	0.09	0.95	0.005	0.19	0.03	0.040	Bal

2.3 Welding Process

Two welding process were used to carry out the welding of the pipe and elbow. GTAW for the root and hot pass and SAW for fill up and capping. The pipe and elbow were having diameter of 42 inches (1067 mm) and thickness of 52.07 mm respectively. The pipes were having a Compound V groove of 40-50° included angle with 4.00 mm root gap. It is better to have a compound V or J groove for welding as it can save more time and welding consumables by reducing weld deposit volume. Low residual filler wires were used for both the welding process. For GTAW, ER90S-B9 Metrode/U2TG153723 was used. Argon gas was used for shielding and backing purpose at a rate of 18-25 LPM (Liters per minute). A DC current with EN polarity was used to carry out the GTAW process. For SAW, EB-91 Metrode U2SW152366 Filler wire and LA490/U2FX162155 flux were used. EP polarity was used for SAW process. The welding consumables should be maintained in the apt temperature in a mother oven or a portable oven. The fluxes shall be baked at about 250°C. The welding parameters play an important role in determining the quality of the weld. Parameters were scrutinized regularly to avoid cracks and we would like to share the best parameters obtained for getting better weld.

Table 3: Recommended welding parameters

PARAMETER	CURRENT (Amps)	VOLTAGE (Volts)	TRAVEL SPEED (mm/min)	WIRE FEED SPEED (cm/min)	OVERLAP
Root & Hot Pass (GTAW)	120-190	11-14	42-130	NA	NA
Fill up(SAW)	350-400	20-29	400-460	170-180	NA
Capping(SAW)	400-450	24-30	500-600	185	50% Min

2.4 Heat Treatment

2.4.1 Preheating

Preheating is the process applied to raise the temperature of the parent steel before welding. It is used for the following main reasons:

- To slow the cooling rate of the weld and the base material, resulting in softer weld metal and heat affected zone microstructures with a greater resistance to fabrication hydrogen cracking.
- The slower cooling rate encourages hydrogen diffusion from the weld area by extending the time period over which it is at elevated temperature (particularly the time at temperatures above approximately 100°C) at which temperatures hydrogen diffusion rates are significantly higher than at ambient temperature. The reduction in hydrogen reduces the risk of cracking.

In this particular experiment the Pre heat temperature was maintained 210 °C prior welding.

2.4.2 Inter-pass heating

Inter-pass temperature is the temperature at which subsequent weld runs are deposited. Welding Procedure Specification(WPS) can specify a maximum inter-pass temperature, which is done to control weld metal micro structural development, and also ensures that the weld is similar to the welds made in the Procedure Qualification Record(PQR). For high alloy materials, it can be important to allow the weld to cool to below the transformation temperature between passes, as too high an inter-pass temperature will allow the weld to remain austenitic. Hydrogen has a higher solubility in austenite than ferrite, and also a slower diffusion rate, so if the weld is austenitic throughout welding, less hydrogen will escape from the steel and cracking may occur upon final transformation. The transformation from austenite to ferrite between passes also allows micro structural refinement or tempering, from heating by subsequent passes. Maximum inter pass temperature was 370°C in this experiment.

2.4.3 Post Heating

Post-heating refers to the maintenance of preheat after the weld has been completed, to allow increased rates of hydrogen evolution from the weld to occur. The post-heat temperature may be the same as, or greater than, the original preheat temperature specified. Post-heat requires full control over time and temperature, to be effective in the removal of hydrogen from the weld, and controlled techniques incorporating thermocouples are preferable. Hydrogen bake-out is a technique closely related to post-heat. Post-heat is a fabrication hydrogen evolution process. Hydrogen bake-out is usually done during repair or modification of a component which has seen service in a hydrogen environment, to reduce the hydrogen that has been introduced in service, before attempting to weld the component. Hydrogen release is a term often used to refer to both or either of these processes. In this experiment, Post heating was carried out at 310°C for one hour

2.4.4 Post Weld Heat Treatment (PWHT)

Post Weld Heat Treatment (PWHT), or stress relief as it is sometimes known, is a method for reducing and redistributing the residual stresses in the material that have been introduced by welding. The extent of relaxation of the residual stresses depends on the material type and composition, the temperature of PWHT and the soaking time at that temperature. A commonly used guideline for PWHT is that the joint should be soaked at peak temperature for 1 hour for each 25mm (1 inch) of thickness, although for certain cases a minimum soak time will be specified.

In addition to reduction and redistribution of residual stresses, PWHT at higher temperatures permits some tempering, precipitation or ageing effects to occur. These metallurgical changes can reduce the hardness of the as-welded structure, improving ductility and reducing the risks of brittle fracture. In some steels, however, ageing/precipitation processes can cause deterioration in the mechanical properties of the steel, in that case, specialist advice should be taken on the appropriate times and temperatures to use. The necessity for PWHT depends on the material and the service requirements. Other factors that influence the need for PWHT are the welding parameters and the likely mechanism of failure. In some standards, PWHT is mandatory for certain grades or thicknesses, but where there is an option, cost and potential adverse effects need to be balanced against possible benefits. For P91 materials PWHT is mandatory requirement and in this particular experiment PWHT was carried out with a soaking time for five hours at 750°C.

Note: For heating, we recommend an induction heating method compared to resistance heating because the former offers a uniform and continuous heating throughout while the latter has some heat losses. Induction heating offers an attractive combination of speed, consistency and control. With induction, the part to be heated never comes into direct contact with a flame or other heating element; the heat is induced within the part itself by alternating electrical current. As a result, product warpage, distortion and reject rates are minimized.

2.5 Overlap

Overlap is an imperfection at the weld toe of a weld caused by molten metal flowing on to the surface of the parent material without fusing to it. The major reasons are contaminated weld preparation, too slow travel speed, too low arc energy, poor welding technique and Position of work. It can be controlled by increasing the travel speed, increasing the arc energy, correcting position of work and Improving the welding technique

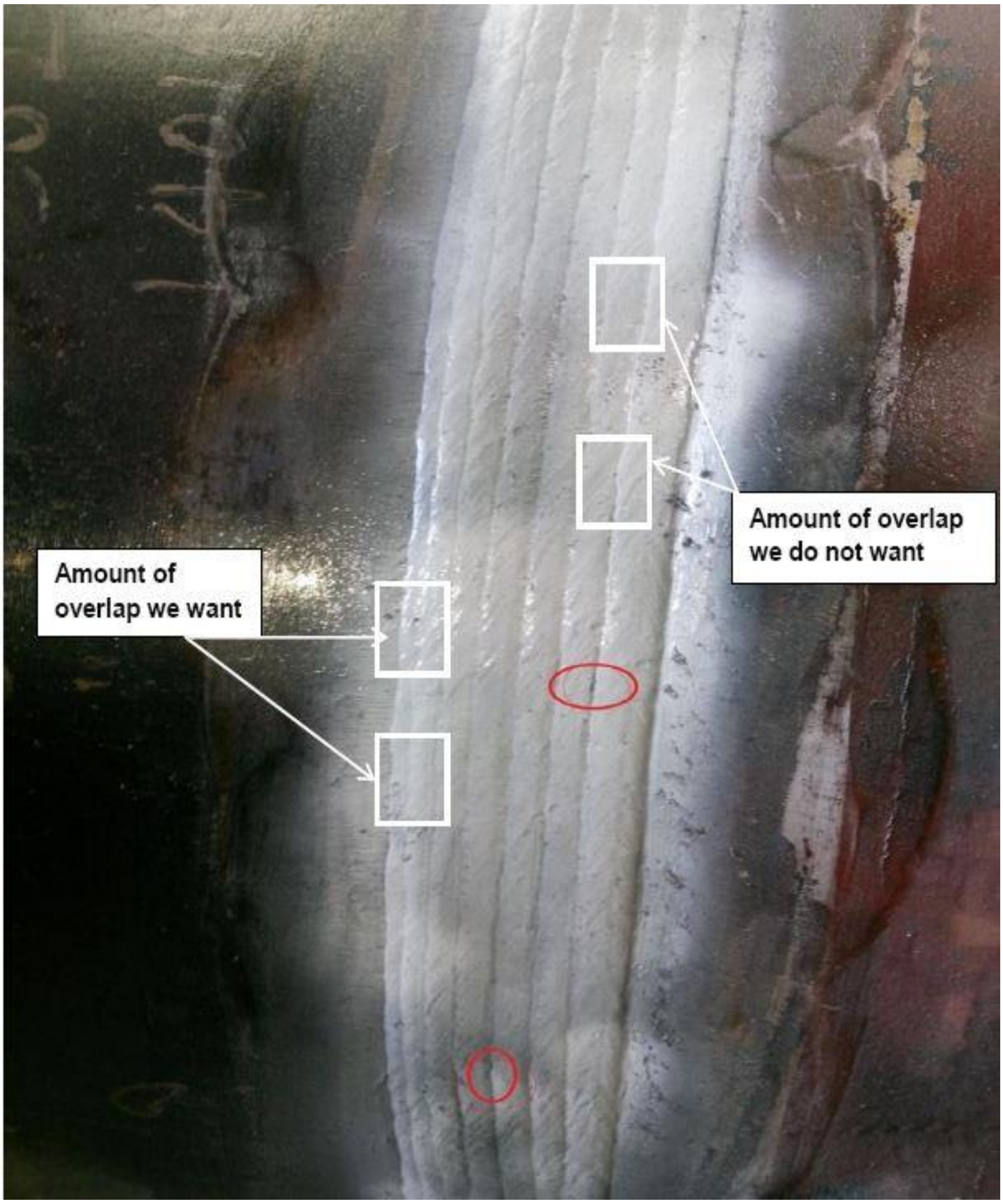

Fig 2: Overlap required for a good weld

3. Results and Discussions

Welding P91 material is a tedious task. It offers poor weldability because of its high strength and complex structure. Welding P91 pipe requires utmost care as it requires lot of heat treatments like pre heating post heating and PWHT. Since it is a complex material low residue filler material is mandatory. While welding the parameters should be carefully followed and monitored irrespective of process.

Cracks are not at all acceptable in any welds. Especially for pipes used for high temperature and high pressure services, even a small crack may lead to a catastrophic disaster. Therefore, cracks need to be eliminated at any cost. The longitudinal crack occurred in the P91 material was eliminated using the above mentioned methods. The parameters and the temperature had a huge impact in formation of cracks. If any of the parameter or temperature is not followed, there are chances of crack formation. The parameters we developed were result of continuous monitoring and evaluation that was carried out throughout the experiment.

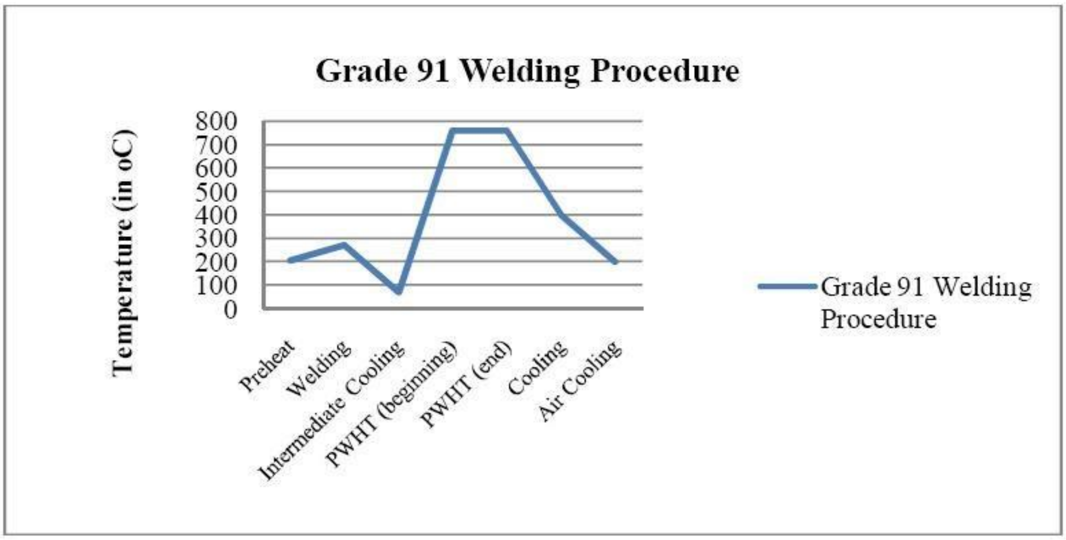

Fig 3: Temperature used in the welding and heat treatment of P91 material

4. CONCLUSIONS

The crack growth behavior of 9 Cr-1Mo V (P91) steel was investigated thoroughly. The crack formation was due to various reasons which were studied in detail and effective remedies were found out. From the experiment we can conclude that

- By controlling the parameters and ensuring proper heating the longitudinal cracks can be controlled.
- There was tremendous decrease in longitudinal cracks that appeared throughout the weld when the parameters and proper heating were ensured.
- If the parameters or heating are not followed intact cracks will occur in the material

- The welds exhibited better quality and was found defect less in the subsequent NDT activities

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