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Effect of Post Weld Heat Treatment on Mechanical Properties and Microstructure of P11 Weld: A Review

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Abstract

Post weld heat treatment (PWHT) is a process of reducing residual stresses and enhancing material properties of any material after welding. The process depends on many parameters like type of material, thickness of material, PWHT temperature, soaking time, heating and cooling rate, etc. Post weld heat treatment is a process of material that could result detrimental effects on tensile strength, yield strength, impact toughness, hardness, elongation, etc. If the process of post weld heat treatment is performed incorrectly, residual stresses in material combine with external loads which may exceed material's design limit. In the present study, different post weld heat treatment failure and its effects on material properties and microstructure is studied in detail.

Keywords: *Welding process, PWHT, microstructure, mechanical properties, PWHT parameters, P11 weld*

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INTRODUCTION

Welding is a common process of joining two pieces using fusion between those two parts. There are many welding processes available in the market like Oxy-fuel welding, GTAW, SMAW, SAW, GMAW, FCAW, ESW, ERW, plasma welding, etc. Type of welding used is according to type of material, thickness, application, properties required, etc. There is a wide range of energy sources accessible for welding which includes an electric arc, a gas flame, a laser, an electron beam, friction, and ultrasound. In the earlier time the only welding process known was forge welding and after that in the end of 19^{th} century arc welding, oxy-fuel welding, and electric resistance welding comes in picture. After that in early 20^{th} century after the world war to create inexpensive and reliable joining methods, all the other welding technologies developed rapidly. A segment where the welding is done is called as weld geometry. There are basic five types of weld joints which are lap, corner, edge, butt, and tee joint. The Figure 1 demonstrates the principle of arc welding process.

After the welding procedure, there are different areas found on weld in which, the part of the weld is known as fusion zone, it is the place where the electrode or filler metal join the parts. Fusion zone properties depend on filler or electrode and its compatibilities with the base material. Fusion zone is encompassed by the HAZ which, depending on the base material's behavior when subjected to heat. These portions are weaker than both the weld and the base material and also where the residual stresses found the most.

According to type of material, its thickness and application of the material, prior and post welding treatments are done which are preheating, post heating, post weld heat treatment etc.

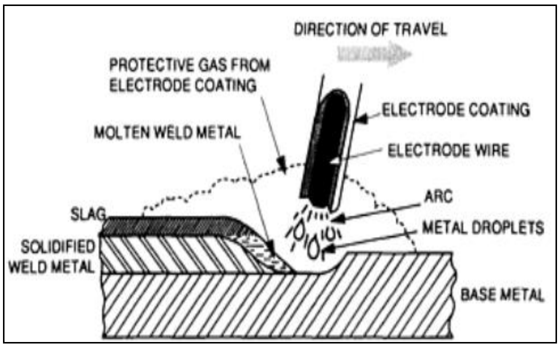

Fig. 1: *Arc Welding Setup* [1].

P11 is an alloy steel material which is particularly suitable for high temperature applications. It is also known as 1.25 Cr-0.5 Mo materials according to its chemical composition.

POST WELD HEAT TREATMENT

Post weld heat treatment is known as heat treatment process after welding, it is used to improve the properties of materials and to reduce residual stresses. The need of post weld heat treatment is driven by codes, application requirement, and service environment. There are mainly three phases in post weld heat treatment as shown in Figure 2:

1) Heating of material at post weld heat treatment temperature,
2) Holding or soaking at post weld heat treatment temperature for some time,
3) Cooling of material to room temperature.

Post weld heat treatment temperature and holding/soaking time are different for different materials according to type of material. ASME standards B 31.1 and B 31.3 for ‘Power Piping and Process Piping’ respectively gives post weld heat temperature, heating and cooling rates, and holding time parameters according to material type and its thickness. AWS D 10.10 also gives the requirements of ‘Heating practice for pipe and tube’.

According to ASME B31.3 standards, P11 material having thickness more than 13 mm should be post weld heat treatment after welding at 650 to 705℃ temperature with holding time of 1 hour per 25 mm thickness.

Here are some studies done in post weld heat treatment parameters on different material.

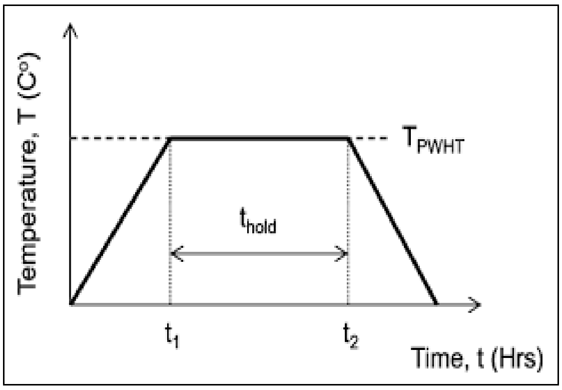

Fig. 2: *Post Weld Heat Treatment Cycle [2].*

G. Thomas, *et al.* did post weld heat treatment of aerospace steel with different conditions for analysis of microstructure and mechanical properties [3]. C. Smith, *et al.* did analysis of long PWHT on A302 Grade B material for 3, 20, and 40 hours of residual stress and mechanical properties [4]. G. Pimenta, *et al.* did analysis of long post weld heat treatment on ASTM A-516 G70 steel for mechanical properties [5]. P.C. Chung, *et al.* did analysis of different post weld heat treatment temperatures on microstructure and mechanical properties of X65 grade and fine grained steels [6]. Pingsha Dong, et al. did the furnace based uniform post weld heat treatment by finite element and analytical method to examine residual stresses for different post weld heat treatment parameters like temperature, holding time, and thickness of material [2]. Junyu Zhang, *et al.* did analysis of post weld heat treatment on material properties and the microstructure of dissimilar joint at a different post weld heat treatment temperature [7]. S. Riyaz Ahmed, *et al.* studied the effect of different post weld heat treatment on material properties of A387 G22 SMAW weld with different post weld heat treatment soaking time of 0.5–50 hours [8]. M.S. Zhao, *et al.* studies post weld heat treatment for S690 high strength steel weld of different thickness at different post weld heat treatment temperature and soaking time for the analysis of mechanical properties [9].

POST WELD HEAT TREATMENT (PWHT) FAILURES

Failures of post weld heat treatment occurred due to many reasons like wrong welding procedure, welding defects, hydrogen level in the weld or HAZ, residual stresses present in the weld, the sensitive microstructure of the weld and HAZ, excessive heating and cooling rate, etc. Although there are standards to apply the best weld repair post weld heat treatment procedure, but it is not for the particular damaged product or to decide the service lifespan of such repair would prolong.

Alfonso R. Fernandez Fuentes, *et al.* studied mechanical properties and microstructure of the weld repaired P11 steam piping system, which was completed to examine the metallurgical and creeps behavior of post weld heat treatment high temperature components [10].

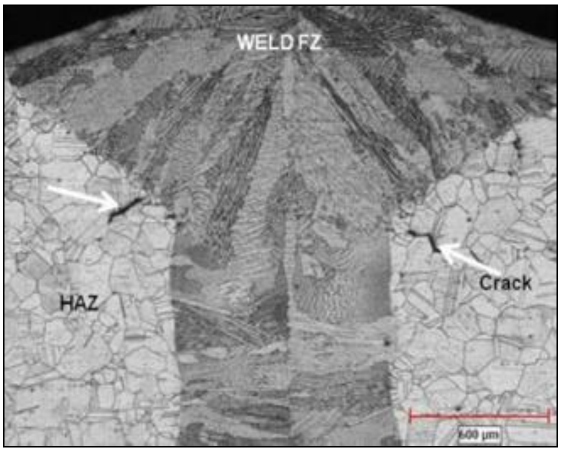

Fig. 3: *Post Weld Heat Treatment Crack [11].*

Here are some other studies done on post weld heat treatment failure and repair on different material.

L. O. Osoba, *et al.* studied on cracking susceptibility after post weld heat treatment in superalloy Haynes 282 as shown in Figure 3 did an analysis of microstructure of HY 282 alloy material and compared it with older post weld heat treatment failures [11]. G. Asala, *et al.* studied post weld heat treatment cracking in TIG welded superalloy ATI 718 plus and conclude that the use of appropriate welding heat input, which may reduce the extent of residual stresses generated during welding can prevent deleterious formation of HAZ cracking during post weld heat treatment [12].

POST WELD HEAT TREATMENT EFFECT ON MECHANICAL PROPERTIES

According to process parameters of post weld heat treatment, material properties like tensile strength, hardness, yield strength, elongation percentage, residual stresses, impact toughness, etc. are varied. To establish any procedure or to perform any kind of experiments on post weld heat treatment, the properties of material are needed to be studied.

According to ASME B31.3 standards, specified minimum tensile strength of >490 MPa and maximum hardness of 225 BHN for P11 material. There setup is shown in Figure 4

Here are some studies for analysis of post weld heat treatment parameter's effects on mechanical properties.

Fig. 4: *Post Weld Heat Treatment Process.*

G. Thomas, *et al.* studied effect of post weld heat treatment on the properties of GTAW welds of Ti-6Al-4V sheet and conclude that hardness of heat affected zone and fusion zone were more than that of the base metal [3]. C. Smith, *et al.* studied the effect of long post weld heat treatment on A 302 Gr B alloy steel and conclude the high heat input reduce impact toughness and also conclude that the elongation generally increases with a longer post weld heat treatment period as the hardness value of HAZ and base metal decreased [4]. G. Pimenta, et al. studies long post weld heat treatment on different steel and concludes that impact resistance decrease with the increase of post weld heat treatment soaking time longer than 6.3 hours [5]. Vigantas Kumslytis, *et al.* studies the effect of post weld heat treatment on mechanical properties of A335 P5 steel welded joints at different temperature and time [13]. P.C. Chung, *et al.* studied the hardness and impact toughness test to evaluate mechanical properties of API x65 electric resistance welded pipe welds [6]. Iman Agha Ali, *et al.* studied the effect of continuous repair on microstructure, hardness, tensile strength, and impact strength for stainless steel grade 316 weld and conclude that material properties are reduced with increasing the number of repairs [14].

Junyu Zhang, et al. studies the effect of PWHT on mechanical properties of dissimilar weld at different temperature and 2 hours of soaking time and concludes that both increase with the PWHT temperature [7]. S. Riyaz Ahmed, et al. studied the effect long post weld heat treatment time on A387 Gr22 of SMAW weld

Table 1: *Literature Review.*

Sr No.	Year	Author's Name	Material	Input Parameters	Output Parameters
1.	1992	G. Thomas *et al.*	Ti-6Al-4V	PWHT Conditions	Microstructure, hardness, UTS, YS, % elongation.
2.	1996	C. Smith *et al.*	A302 Gr B	Soaking time	Microstructure, impact, hardness, YS, UTS, % elongation.
3.	2001	G. Pimenta *et al.*	A516 G 70	Soaking time	Microstructure, UTS, hardness, impact.
4.	2003	Alfonso R. Fernandez Fuentes *et al.*	A335 P11	Weld Repair	Microstructure, creep behavior.
5.	2004	J. R. Cho *et al.*	A131 G 50	Weld thickness	Residual stress.
6.	2010	Vigantas Kumslytis *et al.*	A335 P5	Temperature, Soaking time	Microstructure, impact toughness.
7.	2011	P.C. Chung *et al.*	API X65	Temperature	Microstructure, hardness, impact toughness.
8.	2013	L.O. Osoba *et al.*	HY 282	PWHT Cracking	Microstructure.
9.	2014	Pingsha Dong *et al.*	P91	P91 pipe girth welds	Residual stress.
10.	2014	Iman Agha Ali *et al.*	SS 316L	SMAW	Microstructure, hardness, UTS, impact toughness.
11.	2015	Junyu Zhang *et al.*	CLAM/316L	Temperature	Microstructure, hardness, impact, UTS.
12.	2015	S. Riyaz Ahmed *et al.*	A387 Gr22	Soaking time	Tensile strength, impact toughness.
13.	2016	M.S. Zhao *et al.*	S690	Temperature, Soaking time, Thickness	Residual stress, tensile strength.
14.	2016	G. Asala *et al.*	ATI 718+	PWHT Cracking	Microstructure.
15.	2017	Chandan Pandey *et al.*	P91	PWHT conditions	Microstructure, hardness, impact.

and observed that as the ultimate tensile strength and yield strength reduced as the post weld heat treatment time increasing beyond two hours and also concludes that impact resistance is very less in as welded condition which increase after post weld heat treatment [8]. M.S. Zhao, *et al.* studied PWHT cycle for high strength steel S690 and discovered that the loss of strength and ductility after welding could be able to enhance the ductility of the specimen at the cost of strength' [9] Chandan Pandey, *et al.* studied different post weld heat treatment conditions for mechanical properties and microstructure of P91 steel joint [15].

LITERATURE REVIEW

Literature review is an important part of any review or research paper for understanding:

1. The important aspects of work,
2. A data source that work used three ideas for further consideration, etc.

Here in Table 1, the summary of work or experiments for brief understanding of process parameters and the failures of PWHT with details of paper published and input-output parameters studied by some authors.

CONCLUSION AND FUTURE WORK

From the different research papers, different post weld heat treatment failures with affecting parameters of post weld heat treatment cracking studied. Also, studies show that 75% of residual stresses are relief at post weld heat treatment temperature. Post weld heat treatment temperature and soaking time are the most significant input parameters for post weld heat treatment process and hardness, impact toughness and tensile strength are most significant output parameters to study the post weld heat treatment process.

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