Welding; Properties, Characteristics and Applications in the Geothermal Industry

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ABSTRACT

The geothermal industry is known as a renewable energy source and a clean energy source but inherent properties make this energy anything but clean. Minerals and deposits in geothermal reservoirs create a scale that is persistent in its corrosive nature. Additionally, heat extremes and pressure variations present challenges to the integrity of the wellhead components and the downhole casing. Such challenges must be mitigated to achieve maximum output from these aging or even newly commissioned wells. Certified welding procedures, corrosion and wear resistant welding materials and of course qualified welders are the front line of defense within the industry. We will present a case study showing the need to adopt and follow certified welding procedures as well as evidence of the affects that can happen when these procedures are neglected. Oftentimes one will forego using a certified welder or procedure to accomplish a repair for the sake of budgetary concerns. We will also show the economic impact of using these certified procedures. When considering options for wellhead installation or equipment repair, one must ask some basic but critical questions. Who is going to perform the welding? Is the welding certified, that is does a procedure exist? Is the procedure validated independently? And finally, is the welder performing the work qualified to the procedure? If the answer to all these questions is yes, proceed with confidence.

1. Introduction

Geothermal Energy is a renewable energy source oftentimes overlooked by the public for a myriad of reasons. One chief reason may be that of the similarities, at least on the surface to that of oil and gas production. When one surveys a geothermal power producing site, the similarity in resources and equipment make it difficult to distinguish from oil and gas operations. Similarities do not end with appearances, corrosion and corrosive properties in the fluids extracted are shared as well. For instance, a 1992 report published in Corrosion Engineering notes that coupling dissimilar materials in wells consists of a tubing string made of corrosion-resistant alloy in contact with lower-grade steel casing. These dissimilarly coupled joints also cause crevice corrosion in the occluded area between tubing and casing (Wilhelm, 1992). The problems with do not end with dissimilar metal corrosive properties. Geothermal fluid is inherently highly corrosive, the chemistry to combat the corrosiveness has stemmed an entire industry. The corrosiveness seemingly is a necessary risk for companies to take on when considering operations in the geothermal industry. Corrosion has been addressed and perhaps mitigated, what would one reasonably expect to consider is certainly not the only factor to consider when identifying welding requirements? We will consider the properties o the varying metals, welding materials and the processes by which the welding takes place.

2. Background

Oftentimes welding is associated with the joining of two metals. While this is the end result, many critical details must be considered to perform a successful and satisfactory weld. For example, what material are we welding? What material are we welding to. What is the desired strength of this weld? What is the condition of the existing material? For example, does the customer have ultrasonic thickness readings to show deterioration of the casing to be welded? This is even more important when the casing has been below ground for extended periods. Are there other concerns such as preheating or post-weld heat treating, also referred to as stress relieving? This list of considerations is just the beginning. Below is a table of commonly used casing also found in the geothermal industry.

Group	Grade·	Typ℮_	Total elongation under load	Yield 1itrength MPa		Tensile strength min	Hardness" max.		Sified wi,ll thickness	Allowable hardness variation
			%	min.	max.	rAPa	HRC	HBW	mm	HRC
1	*2*	*3*	*4*	*,5*	*6*	*7*	*8*	*9*	*10*	*11*
1	H4-0	-	0 ,5	276	552	414	-	-	-	-
	J55	-	0,5	379	652	5'17	-	-	-	-
	1<65	-	0 .5	379	552	655	-	-	-	-
	tsl80	1	0,5	552	758	689	-	-	-	-
	J8 0	Q	0.5	552	758	689	-	-	-	-
	R95	-	0,5	655	758	724	-	-	-	-
2	M65	-	0,5	448	586	586	22	235	-	-
	L80	·1	0.5	552	655	655	23	241	-	-
	L80	9Cr	{J°,.,:;	5.52	655	655	23	241	-	-
	L80	13- Gr	0,5	552	655	6-55	2.3	24'1	-	-
I l I	coo	1	0 ,5	621	724	689	25,4	255	>: 1 2,70 1 2,71 to 19,04 1"9,05 lo 2.5,39 ::. 25,40	3.0 4 ,0 I 5.0 1 6,0 I
I l I	T95	1	0.5	655	758	724	25,4	255	12.70 12,71 l o 19,04 1 9,05. to 25.39 ::. 25,40	3,0 4,0 I 5,0 I .6 ,0 I
	c 1 ·10	-	0 ,7	758	828	793	30	286	12,70 12,71to 19,04 · 19 ,05 lo 25,39 :t 25 ,40	3,0 4,0 5,0 6,0
3	P110	-	0.6	758	**965**	862	-	-	-	-
4 I I	**0125**	1	0,65	002	1034	931	t,	-	12J -O 1.2,71 lo 19.04 ::. 19 ,05	J-,0 **4,0** I **5,0** I

Figure 1: American Petroleum Institute, Purchasing Guidelines, API Specification SCT 9th Edition, June 2011

Of particular importance in this table is the tensile strength (the amount of force required to cause a failure) and yield strength (the amount of force required to cause permanent deformities.) The desire of course is that the weld has a higher tensile strength than that of either metal being joined together. For example, a typical wellhead forged from 4130 steel material would be welded to the K-55 casing using an independently verified welding procedure. From this procedure and the table referenced we know two things. One the tensile strength of the casing is 655 MPa (megapascal) or 95,000 psi and the casing head has a yield strength of 560 MPa or

81,220 psi. Two, the tested weld procedure indicates this weld has a tensile strength of 82,000 psi and therefore provides the desired result of the base material failing before the weld. Every verified welding procedure would indicate like results, that is the weld always test to a higher tensile strength than the base metal.

3. Examples

In December 2017, we qualified a welding procedure for a customer at the customer's request. That procedure was developed to weld a casing head flange made of 4130 material to NT80 casing. This procedure was developed by an independent consulting and testing contractor. After many hours of development and testing the actual welding was scheduled. The work was completed according to the welding procedure and scope of work from the customer including customer provided materials. The problem surfaced when it was discovered that the casing head was in-fact not made out of 4130 but rather 4140 material which has a much higher tensile and yield strength. The potential for a failure at the weld now exists as this was not a qualified welding procedure. The correct course of action should have been to develop a welding procedure for this weld actually and qualify the welder to it. If the procedure demonstrates a satisfactory weld, there is no need to further or corrective action.

In September 2018, a welded tab to center casing on L-80 68# casing was applied. The weld was not conducted with any pre-heating and without following any procedure. The resulting weld failed and caused a 4" crack in the casing. The crack was the source of a significant leak in the well and required immediate correction which included a procedure complete with pre-heating the entire area to be welded and post weld heat treat of the weld and affected areas.

Figure 2. Crack in L-80 Casing / Weld Failure: Courtesy of PT TNG Energy Services Indonesia

Now that we see the effects of and the potential consequences of inadequate welding let's look at some ways to avoid these issues.

4. Prevention

A qualified weld procedure such as the one previously mentioned often has two components that have proven to be effective in both weld failure prevention and strengthening the weld. The first is a process known as pre-heat. Pre-heating is a process used to reduce the rate at which a weld cools. A common temperature range in which preheating occurs is between 250º F and 400º F (121 º C to 204 º C) for structural steel which casing qualifies (Jeffus, 2008). This process becomes increasingly important as the carbon content of the casing increases. Such is the case of the L-80 casing. The second component is the process of post-weld heat treating, commonly called stress relieving. Stress relieving removes or reduces residual stresses in the welding surfaces that render them unusable. Stress relieving heats the welding surface to a point that is lower than the transformation temperature. The transformation temperature is the range of temperatures in which steel undergoes internal atomic changes that radically affect the properties of the material (Jeffus, 2008). This temperature is held for a set period and then the surface is allowed to cool slowly. A common temperature range for stress relieving is between 1100º F and 1150º F (593º C and 620º C) which may allow a stress reduction of approximately 90%. Caution must be exercised when allowing the material to cool to avoid rapid cooling thereby introducing stresses to the metal. A qualified welding procedure defines the temperature ranges of both pre-heat and stress relieving, a machine that is computer controlled ensures the predefined temperatures are met.

5. **Conclusion**

As we have seen, many combinations of materials must be welded in the geothermal industry. While the process of welding oftentimes conjures images of a welder "hopping out of the truck" and striking an arc, many factors must be considered. The customer must have a firm grasp of not only the desired results but also the materials, strengths or yields required and well conditions. To achieve the results, the customer would also show due diligence by the ensuring the weld is qualified to a procedure and the welder is qualified to the requested weld procedure. When all these factors have been met one can rest assured that all reasonable efforts to ensure safety and quality have been exercised.

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