ENERGY SAVING TECHNOLOGY IN POWER PLANTS INDUSTRY BY HIGH FREQUENCY RESISTANCE WELDING

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This paper aims at investigating the use of high frequency resistance welding (HFRW) to deploy energy saving technology in power plants industry. The new approach of dissimilar welds A240TP409 finned and 2¼ Cr-1 Mo seamless tube under various conditions of high frequency resistance welding (HFRW) are found in power plant boilers and reducing energy costs is possible through the use of finned tubes. HFRW have accomplished on samples by changing multiple parameters including current of welding, electric potential, travel speed and fin pitch. Microstructural evolution in weld bond, hardness and tensile strength tests revealed that metallurgical bonding more than 90 % was measured at the weld interface and the average of tensile strengths were more than 275MPa, with setting on appropriate welding parameters and optimum pressure. Since the pitch and fin thickness can be severely reduced, the output transfer surface treatment in final process can be dramatically diminished. Lastly, a well-engineered approach to the design of the best conditions of finned tube welding bond is discussed in modern combined cycle power plant (CCPP).

Key words: energy saving; power plants; dissimilar welds; seamless tube

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1 Introduction

Dissimilar metal welds (DMWs) between ferritic steel grades are found extensively in the construction of thermal power plants. The potential combinations and approaches for joining dissimilar ferritic steels are nearly limitless as stated by P. Mayr et al. [1]. Juliermes CP et al. [2] explained that Cr-Mo steels are materials that operate at high pressures and high temperatures, mainly in the petrochemical industries and in the power generation area, this is due to their good corrosion resistance, mechanical strength, and high temper ability, make them effective for working under critical conditions. 2.25Cr-1Mo steels have a stable microstructure with fine carbides that prevent the movement of grain contour disagreements, thus increasing their mechanical strength. D. J. Benton [3] mentioned that these heat exchangers are designed to recover the heat from a gas turbine exhaust and convert this to steam, which drives a turbine and ultimately a second generator. Heat recovery steam generator (HRSG) can be complex to analyse and difficult to effectively test and prove their performance. Y. Wang et al. [4], investigated that the current development in the power generation industry is of increasing demand for combined cycles with improved efficiency and reduced delivery time. Improved efficiency reduces the fuel related cost and, at the same time, contributes to the resolution of the greenhouse effect. Finned tubes position of harp modules in HRSG are key components in the combined cycle. A block of modern combined cycle power plant (CCPP) is demonstrated in (Fig. 1). Increase the rate of heat exchange in the HRSG tubes, the surface area on the outside of the tubes is extended by finning [5]. Finned tubes of headers are routinely used in high temperature applications in which HRSGs are an integral part of any modern CCPP [6]. In the finned tube welding process rolled steel strip is continuously welded in spiral form on the outside diameter of a tube. This type of weld is comprised of a fusion between two portions of parent metal without the introduction of a filler material [7]. The weld is simply produced by heating the interfaces to be joined to a plastic state and applying pressure. Current frequency range normally used for high-frequency welding 400 kHz. [8]. Increase the rate of heat exchange in the HRSG tubes, the surface area on the outside of the tubes is extended by finning. It can be used as: heaters, economizers, or super heaters [9].

Manufacturing process of finned tube is illustrated in (Fig. 2) by HFRW technology. There are several technologies of making finned tubes and J. Adamiec et al. [10, 11] studied that the laser welded joints of fin tubes made of alloy Inconel 625 are resistant electrochemical and pitting corrosion in the base material. High-frequency welding is a solid resistance heat energy. The use of high-frequency current welding resistance heat generated within the work piece so that the work piece surface is heated to melt the weld zone or close to a plastic state, then applied (or not applied) upsetting force to achieve binding metal [12]. It is a solid-phase resistance welding methods, with this technique, the fin is wound on edge around the tube spirally and a continuous weld is obtained [13]. The high frequency resistance welding process produces a strong metallurgical bond between the fin and the tube while minimizing the heat affected zone (HAZ) in the tube as stated [14].

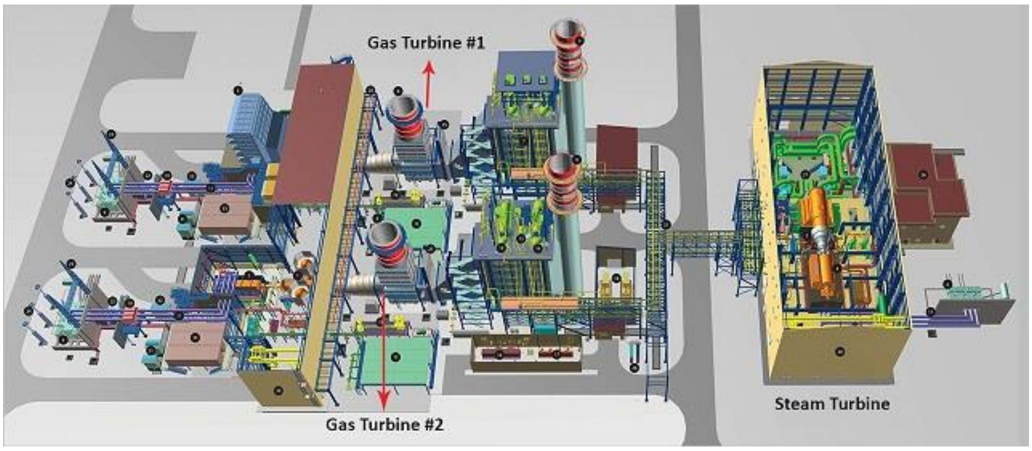

Fig. 1 A block of modern combined cycle power plant (CCPP)

Fig. 2 Manufacturing process of finned tube by HFRW technology

The fins greatly enhance the heat transfer surfaces, allowing the full optimization of heating surfaces of the boiler, which is achieved by reducing the dimensions of the boiler, and thus reducing its weight [15]. As shown in Kushima H. et al. [16] metallographic atlas for 2¼ Cr-1 Mo steels and degradation due to long-term service at elevated temperatures. King B. [17] performed that Welding 2¼ Cr-Mo steel is to use preheat and post welding heat treatment (PWHT) to improve weldability. Wagner Ferreira L. et al. [18] indicated that microstructure evolution and creep properties of 2¼ Cr-1 Mo carried out. The observations of the ferrite-bainite steel show a more stable behaviour at the ageing temperatures and time considered and creep tests revealed that the ferrite-pearlite microstructure possesses a better rupture time performance. Zuback S. et al. [19] demonstrated that dissimilar joints between 2¼ Cr-1 Mo steel to austenitic alloy has been studied. Ornek C. [20] observed the position of A240T409 finned the lowest chromium content of all stainless steels in Schaeffler diagram.

2 Experimental part

2.1 Samples

Compared to other conventional welding processes, HFRW finned tube technology uses a significant energy saving in which the absence of flux or cover gas makes the process environmentally safe. Chemical composition A240TP409 is titanium stabilized ferritic stainless steel (FSS) cold rolled of coil strips containing about 11 % chromium shown in Table 1.

Table 2 presents the chemical composition of the 2¼ Cr-1 Mo material used in this study by an optical emission spectrometer. Serrated finned tubes and solid finned tubes are two types of spiral wrapped finned tubes used HF as illustrated in (Fig. 3).

Table 1 Chemical composition (% wt.) of the FSS

Steel Finned	C	Mn	P	S	Si	Cr	Ni	Ti
FSS	0.06	0.29	0.020	0.015	0.57	11.14	0.14	0.19

Table 2 Chemical composition (% wt.) of the 2¼ Cr-1 Mo boiler seamless tube

Boiler seamless tube	C	Mn	P	S	Si	Cr	Mo
2¼ Cr-1 Mo	0.12	0.40	0.013	0.003	0.23	2.15	0.93

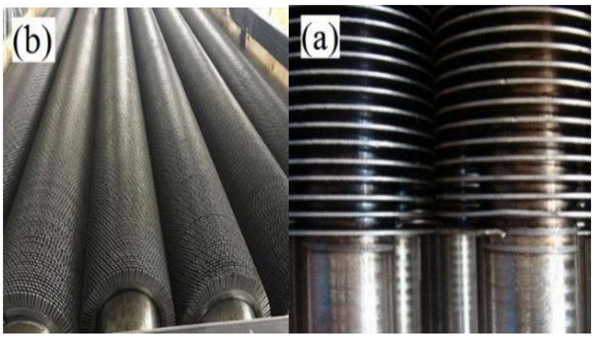

Fig. 3 Type of finned tubes HFRW process (a) Solid finned tubes (b) Serrated finned tubes

2.2 Welding parameters

Serrated and solid fins are widely used solutions for improving heat transfer in fired heaters. The important fact that designers often overlook while selecting the fins is that serrated fins can provide larger surface area and significantly higher fin efficiency compared with solid fins. Sample preparation of finned tubes welding include sample of weld bond tests, tensile strength and hardness tests were prepared as illustrated in (Fig. 4).

Fig. **4** Sample tests preparation of 2¼ Cr-1 Mo seamless tube and A240TP409 finned tubes

In this research 4 essential welding parameters including welding speed (travel speed), current electric potential, and pitch were assumed as variables and 10 simples were selected by Taguchi method and welding process was performed according to the conditions mentioned in Table 3 by “HANSUNG HFS-9488pu” HFRW machine.

2.3 Metallography and Mechanical test

Metallography for welding bond was done by Olympus DMI3000M optic microscope which was equipped with Image Analyzer. The dimension of 2¼ Cr-1 Mo steel tube for welding experiments 38.1×2.9 mm were selected. According to ASTM E340-20, 8 samples were prepared for metallography test. Tensile strength (1 mm/min) was done by SANTAM-STM-60. The quantity of test piece is 6 per 1 tube. The minimum value of tensile strength is 275 MPa for weld applied according to ASTM A370-20. Hardness test was done by DRMC-250. The weight was 500 gram-force and the time was 15s in 4 connecting positions. Alloy steel and stainless steel samples require Micro hardness HV1 (Vickers diamond 136° indenter). The hardness test was carried out at 3 points (Fin, HAZ, and Tube) per each sample. Hardness at heat affected zone (HAZ) shall be under 150Hv for fin tube according to ASTM E384-20.

Table 3 HFRW Welding parameters of sample test

Sample No.	A213T22 Tube O.D. × Thickness	A240TP409 Finned Width× Thickness	Travel Speed (RPM)	Potential Welding (V)	Electric Current (A)	Pitch (Fins/Meter)
1	38.1×2.9	17×1.2	560	10.8	12.9	126
2	38.1×2.9	17×1.0	540	10.5	12.3	126
3	38.1×2.9	17×1.2	520	11.2	13.4	180
4	38.1×2.9	17×1.0	520	11.0	13.1	180
5	38.1×2.9	17×1.2	500	11.5	13.9	240
6	38.1×2.9	17×1.0	500	11.4	13.8	240
7	38.1×2.9	17×1.2	480	11.7	14.0	276
8	38.1×2.9	17×1.2	480	11.8	14.2	276
9	38.1×2.9	17×1.0	430	12.1	14.5	305
10	38.1×2.9	17×1.0	460	12.3	15.1	305

3 Results and Discussion

The microstructure for A213T22 (2¼ Cr-1 Mo) Seamless Tube is shown on (Fig. 5a). The microstructure consists of ferrite (light etching constituent) and a small amount of pearlite (dark etching constituent). As well as the microstructure of ferritic grade of type 409 stainless steel finned is illustrated that (Fig.5b).

A straight chromium steel in which the carbon is deliberately kept as low as to have a negligible hardening effect is classified as ferritic. The chromium content is usually above 11 weight-percent with low carbon and no nickel, these alloys are permanently ferritic. It is shown the ferritic structure with smaller grain size for the stainless steel 409. In the case of grade 22, the formation of ferrite is partially displaced by the introduction of a bainitic phase transformation, according to continuous cooling transformation (CCT) diagram for 2¼ Cr-1 Mo steel is shown in (Fig.6) according to Schaeffler diagram, in this case, the amount of chromium and nickel equivalent is display in (Fig.7). The examined specimen’s steel had ferrite type.

The microstructure is shown that (Fig.8a) finned to tube joints relevant to sample 100 % welding bond. The average width of the weld bond between finned and tube shall be a minimum of 90 percent, according to standard specification for HFRW finned tubes. The microstructure of rejected sample is demonstrated in (Fig.8b) uncompleted welding 81 %.

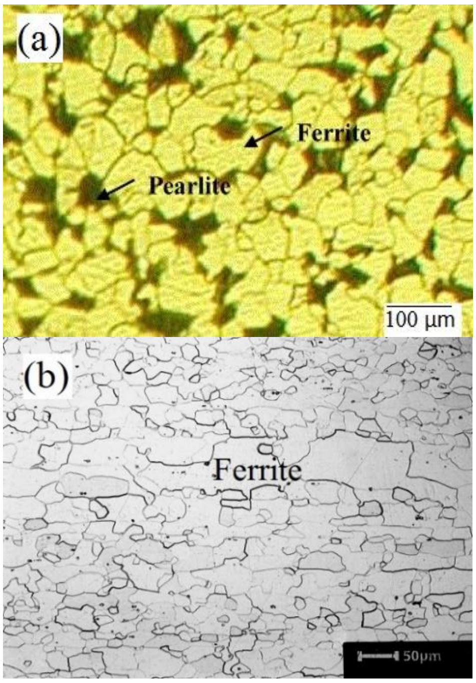

Fig. 5 The microstructure of base metal (a) A213T22 (2¼ Cr-1 Mo) seamless tube (b) A240TP409 finned

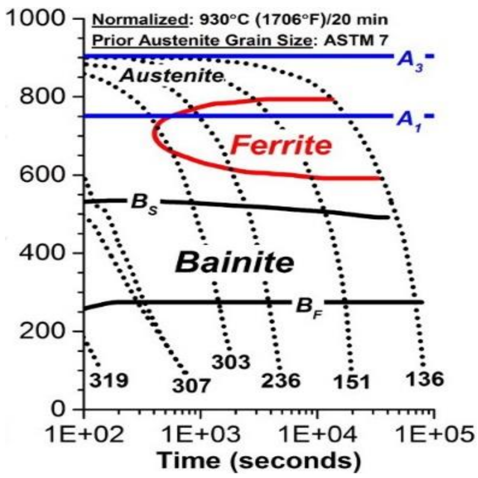

Fig. 6 CCT diagram for A213T22 (2¼ Cr-1Mo) seamless tube finned tubes

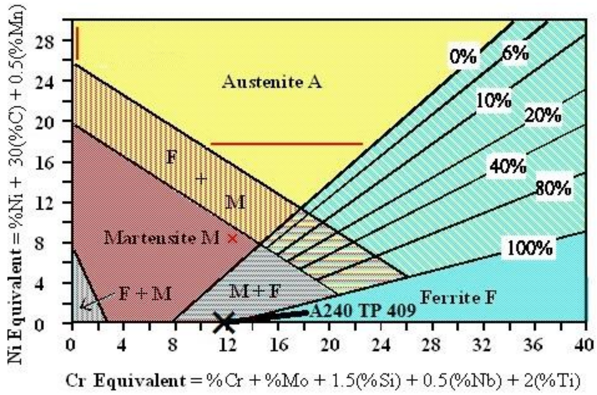

Fig. 7 The position of A240TP409 ferritic finned in Schaeffler diagram

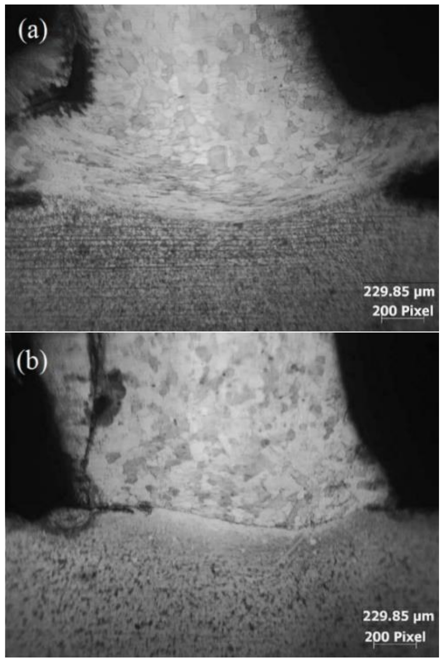

Fig. 8 The microstructure of A213T22(2¼ Cr-1 Mo) Seamless Tube to A240TP409 ferritic finned (a) Accepted specimen: 100 % weld bond (b) Rejected specimen: 81 % weld bond

Furthermore, the result of Table 4 is shown that on 10 average welding specimens, the diffusion zone indicating metallurgical bonding more than 90 % was measured at the weld interface all of the tests, with applying optimum welding parameters, fin-tip and tube-tip position and setting on squeeze rollers with hydraulic pressure jack (air pressure of fin tip holder is 0~4 kg/cm2 and air pressure of tube tip holder 0~5 kg/cm2) and fin pitch. The arithmetic average width of the weld bond as evidenced by the white metal exposed will no less than 90 percent of the measured fin thickness in the fractured surface of the fin-to-tube weld.

Table 4 Average of welding bond sample

No.	Fin to tube weld bond	Result
1	100 %	Accepted
2	100 %	Accepted
3	96 %	Accepted
4	100 %	Accepted
5	97 %	Accepted
6	98 %	Accepted
7	100 %	Accepted
8	100 %	Accepted
9	100 %	Accepted
10	100 %	Accepted

Schematic fin weld width and penetration demonstrated in (Fig. 9). Tensile strength curves of 6 fin joints to tube illustrated that (Fig. 10a) rejected sample and

(Fig. 10b) accepted sample. As well as the result of tensile strength is displayed in Table 5 rejected specimens and Table 6 accepted specimens.

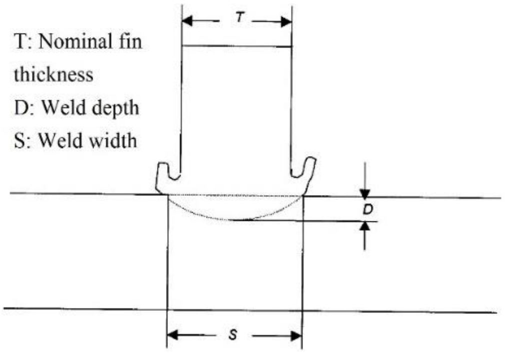

Fig. 9 Schematic fin weld width and penetration

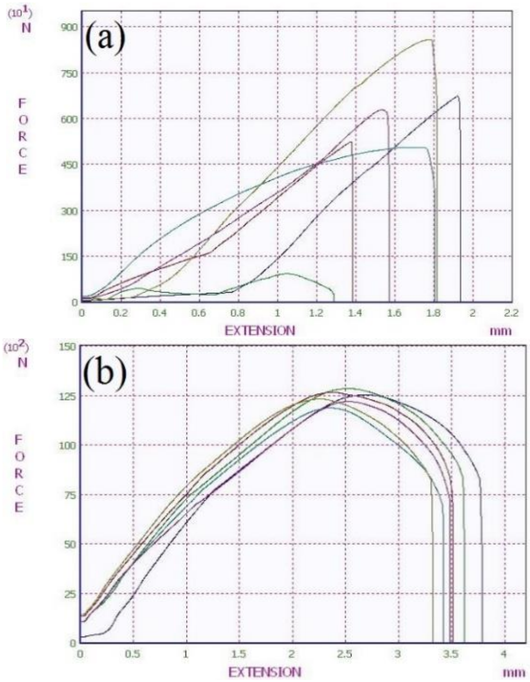

Fig. 10 Tensile strength tests of tube to fins according to ASTM A370-20 (a) rejected specimens (b) accepted specimen

Table 5 Result of tensile test (6 fin joint to tube) rejected specimens

Rejected specimens	Thickness (mm)	Sec. Area (mm^2)	Total load (N)	UTS (MPa)	Location of failure
T1	1.2	28.692	6739.27	244.27	Weld
T2	1.2	25.392	9863.14	924.8	Weld
T3	1.2	27.612	5817.53	5058.28	Weld
T4	1.2	26.712	9188.7	5236.09	Weld
T5	1.2	27.84	7176.63	6289.64	Weld
T6	1.2	26.28	726.55	8576.6	Weld
Result			REJECTED		

Table 6 Result of tensile test (6 fin joint to tube) accepted specimens

Accepted specimens	Thickness (mm)	Sec. Area (mm^2)	Total load (N)	UTS (MPa)	Location of failure
T1	1.2	26.292	12524.1	476.35	Fin
T2	1.2	26.868	12838.84	477.85	Fin
T3	1.2	26.298	11862.95	440.54	Fin
T4	1.2	26.772	12653.88	472.65	Fin
T5	1.2	27.48	12193.01	443.70	Fin
T6	1.2	27.91	12317.68	441.50	Fin
Result			ACCEPTED		

Table 7 is shown that result of tensile strength (6 fin joints to tube) in 10 average welding specimens. Furthermore, all tests were accepted because the average of tensile strengths were more than 275MPa.

Table 7 Average UTS of welding specimens

No.	UTS (MPa)	Result
1	440.36	Accept
2	378.39	Accept
3	375.34	Accept
4	377.85	Accept
5	400.32	Accept
6	381.15	Accept
7	380.17	Accept
8	458.76	Accept
9	375.61	Accept
10	379.73	Accept

Table 8 is shown the hardness of the specimens according to the conditions indicated in table 3 at various zones. The results of hardness test in Table 8 show that the highest hardness in HAZ alloy steel tube 272 HV was related to specimens No.8 and the lowest hardness in alloy steel tube 251 HV was related to specimen No.4.

Table 8 Hardness results of various specimens (HV)

No.	Fin HAZ	Hardness variation of fin to fin HAZ	Tube HAZ	Hardness variation of tube to tube HAZ
1	174	151	252	168
2	162	164	270	166
3	165	156	263	163
4	170	149	251	167
5	166	160	264	165
6	171	150	267	168
7	169	148	265	164
8	161	162	272	165
9	172	159	262	162
10	164	161	258	164

As well as the highest hardness in HAZ St-St finned 174 HV was related to specimen No. 1 and the lowest hardness in HAZ St-St finned 161 HV related to specimen No. 8. The most hardness variation between HAZ fin to fin 164 HV related to specimen No. 2 and the most hardness variation between HAZ tube to tube 168 HV related to specimen No. 1. The result of hardness test that according to ASTM E384-020 standard all of the hardness specimens were in acceptance criteria, as well as in Table 9, one rejected specimen was provided just to be compared with accepted specimens.

Table 9 Hardness result of rejected specimens

No.	Hardness (HV)			
	Fin HAZ	Hardness variation of fin to fin HAZ	Tube HAZ	Hardness variation of tube to tube HAZ
1	201	186	275	175

Serrated and solid types of fin tube produced by HFRW depend on fin height, fin thickness and tube O.D. The result of analyzes show that as the lower pitch and fin thickness are selected, the higher quality of fin tube welding bond is achieved. On the other hand, as the pitch and fin thickness can be severely reduced, the output transfer surface treatment in final process can be dramatically diminished. Since increasing performance in the aspect of process design and welding engineering, the range can be set on optimum the current electric welding, potential welding and travel speed of welding. Furthermore, selecting suitable finned include 1 mm fin thickness, 15 mm fin high and 276 per meter of fin pitch has been achieved.

4 Conclusions

HRSG is obviously a very desirable energy source, since the product is available almost operating cost-free and increases the efficiency of the cycle in which it is placed. Increasing thermal efficiency while reducing energy costs is possible through the use of finned tubes for heat exchangers by high frequency resistance welding. In this investigation, the energy saving technology in power plants industry by high frequency resistance welding (HFRW) finned tube need to manufacture power plants industry. The following conclusions can be drawn from this work:

- Compared to other conventional welding processes, HFRW finned tube technology uses a significant energy saving in which the absence of flux or cover gas makes the process environmentally safe.
- Metallurgical bonding more than 90 % was measured at the weld interface, with setting on appropriate welding parameters and optimum pressure.
- Water spray lead to the grain size in microstructure and HAZ limited in section welding so that the average of tensile strength more than 275 MPa.
- The key factor produced HFRW depend on fin high, fin thickness and tube O.D. in solid and serrated types of spiral finned tube.
- The best conditions of finned tube welding bond is achieved by 276 per meter of fin pitch, over 15 mm fin high and 1 mm fin thickness.

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