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Simulations of Rectifications which are Needed in Dynamic Wire and Hot Wire GTAW of 304HCU Tubes of Reheaters and Superheaters using ANSYS 2021

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ABSTRACT

The aim of this project is to simulate the rectification that are needed in hot wire and dynamic wire gas tungsten arc welding of reheater and superheater tubes made of 304hcu ss using a simulation software like ansys 2021. The given grade of stainless steel is of 300 series with chromium and nickel austenitic stainless steel are non hardenable by heat treating and corrosion resistant. 304 hcu ss has a better microbiologically influenced corrosion resistance. The gas tungsten arc welding (gtaw) process: also known as tig welding, it is an electric arc welding process in which the fusion energy is produced by an electric arc burning between the workpiece and the tungsten electrode. It differs from other arc welding processes by the fact that the electrode is not consumed like other electric arc welding process. To prevent hot cracking, welding with a heat input below 2 kj/mm, using an interpass temperature below 150 °c, is recommended. To avoid stress corrosion cracking, contact with certain solutions, particularly those containing chlorides should be avoided. Extra care needs to be taken during plant shutdowns as chloride containing condensates can be formed leading to stress corrosion cracking. However, cracking requires the presence of high stresses and is therefore more likely to occur in thicker sections, t- joints, like header-tube connections, or joints with dissimilar metal thickness, where the higher restraints can lead to higher residual stresses after welding than in thin-walled superheater/reheater tubing with butt welds.

Keywords**—** GTAW, Wire, Rectification

II. INTRODUCTION

FEM Analysis

Chemical Composition of 304Hcu

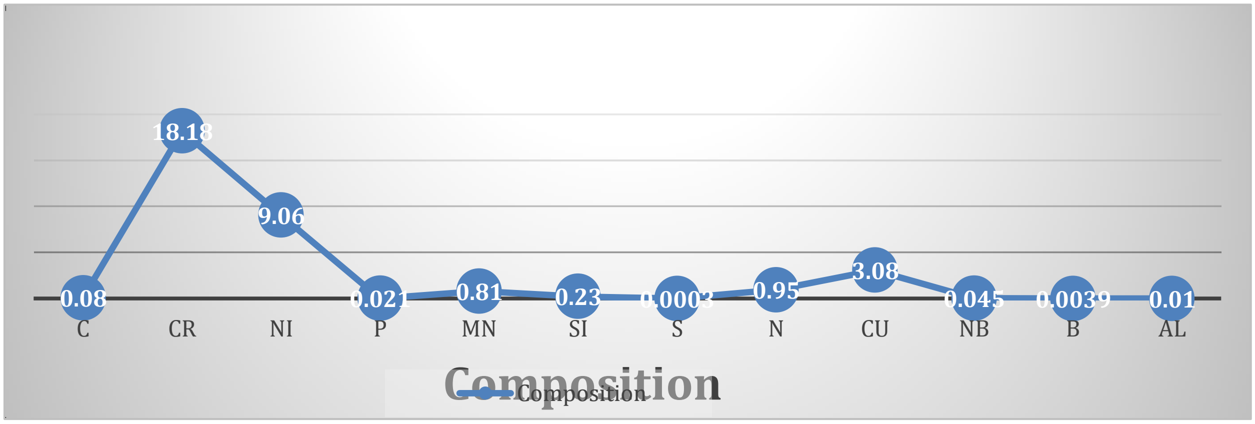

Figure 2.1: Chemical Composition of 304 Hcu

The requirements with regard to chemical composition are summarized in Figure 2.1. The composition given in the ASME Code Case is the same as that given for the cast analysis in the VdTÜV materials data sheet 550 (09.2003). A solution treatment at a temperature of at least 2,000 °F (1,100 °C) is performed before delivery. The major material used is 304 SS with the added Carbon and Chromium content with various other materials as described in Figure 2.1

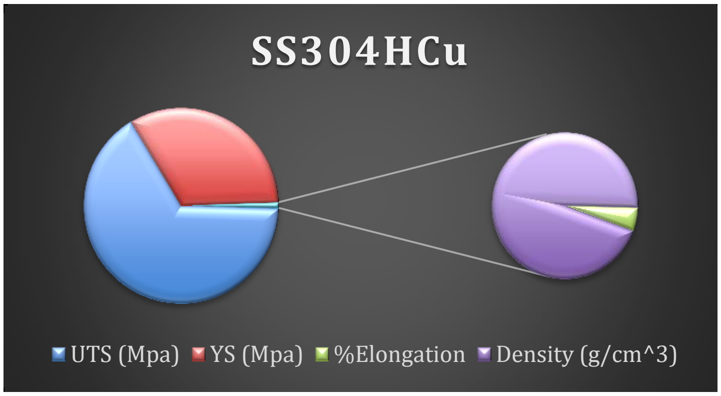

Figure 2.2: Mechanical properties

Tensile properties at room temperature in the solution-annealed condition according to the ASME Code Case are given in graph 2. The steel grade 304 HCu is an 18Cr8Ni austenitic stainless-steel. Differences in material properties and particularly within the creep resistance compared to the traditional grade 304 are mainly achieved by addition of about 3 wt.-% of copper. The formation of fine Cu-rich precipitates during service ends up in an increased creep strength by the mechanism of precipitation hardening. Additionally, an increased carbon, niobium and nitrogen content are effective compared to the traditional grade. The fabric properties are influenced by the precipitation of niobium carbonitrides, M23C6 carbides and NbCrN. A high phase stability during long run aging is achieved. The material meets the applicable requirements of ASME SA-213 specifications. The desired material properties are further described within the ASME Code Case 2328-1: 18Cr-9Ni-3Cu-Nb-N. Austenitic stainless steel is an alloy, which is iron based and contains major elements Cr and Ni to give it characteristics suitable for a wide range of applications. SUPER 304H austenitic stainless steel is used for boiler plant heat exchanger tubes to increase the efficiency that contain minimum of 17-19% chromium and 7.5-10.5% nickel. SUPER 304 stainless steel is used in chemical, petrochemical and fertilizer industries and as equipment in dairy, food processing, cryogenic vessels and as heat exchanger tubes. In the various materials for the heat exchanger tubes, the SUS 304H austenitic steel has shown considerable promise due primarily to its high oxidation, corrosion and creep resistances, and relatively low processing cost. Further enhancements in the efficiency of power plants can be achieved by operating at higher steam temperatures, which in turn requires higher creep resistant alloys. In this context, the addition of 3.08 wt.% Cu to SUS 304H, aimed at reducing the recycling cost, has been found to increase the elevated temperature strength of the austenitic steels, especially their creep performance in the temperature range of 650– 750 ◦C. However, it has been proposed that Cu, which gets dissolved in the austenitic matrix, while exposed the welded joints in the temperature range of 650c-750c, which forms precipitates during service, as coherent nano-sized particles. Cu-rich phase within the matrix.

Simulations and Results

Strain and Stress

Table 2.1: Stress/Strain Analysis

Serial Number	Probe	Maximum	Minimum	Average
1	Equivalent Elastic Strain	1.3976×10^{-2}	5.7902×10^{-7}	9.648×10^{-5}
2	Equivalent Stress	2.124×10^{9} Pa	52491 Pa	1.2127×10^{7} Pa

The simulations were conducted taking a pipe of 63.5 mm OD and 300 mm in length and then three similar pipes were welded together. The material was created using conditions mentioned in figure 1 and figure 2. They were subjected to normal stress as to find the equivalent elastic strain and equivalent stress across the welds and pipes. The results are mentioned in Table 1. These results correspond to the mechanical properties mentioned in Figure 2. These results were also cross-checked with the values that are obtained by conventional austenitic grade 304 SS during similar conditions, and they prove to be better.

Heat and Thermal Effects

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Table 2.2: Process Parameters for Dynamic Wire GTAW

Parameters	**Value**
Pulse Current (A)	190
Base Current (A)	150
Average Current (A)	176
Pulse Time (s)	0.4
Base Time (s)	0.2
Pulse Voltage (V)	10.6
Base Voltage (V)	9.9
Average Voltage (V)	10.4
Gas Flow Rate (RPM)	12
Welding Speed for All Cases (cm/min)	7.5
Pulse Wire Feed Speed (m/min)	1.6
Base Wire Feed Speed (m/min)	1.1
Average Wire Feed Speed (m/min)	1.4
Filler Wire Oscillation Frequency (Hz)	20

In this process, a dynamic wire was introduced to the welds in the pipes to further enhance the heat and thermal resistance of the pipes when they are used as boiler and reheater tubes. The parameters are mentioned in Table 2 and the temperature was set to 3000^{o}C. After the material (304HCu SS) was assigned and the parameters were entered accordingly, the simulations were conducted on;

1. Temperature Variation
2. Thermal Error
3. Directional Heat Flux

Also, the same was done for a singular pipe with different dimensions (45mm OD 150 mm Length), to see the variations, if any, for the changed dimensions. The results were the same.

Temperature Variation

Table 2.3: Temperature Variation

Minimum (^{o}C)	**Maximum (^{o}C)**	**Average (^{o}C)**
-203.96	3000	94.609

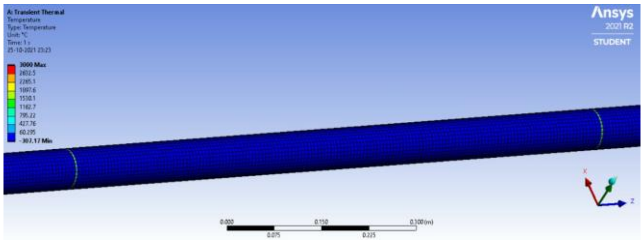

Figure 2.3: Temperature Variation on welds of standard pipe

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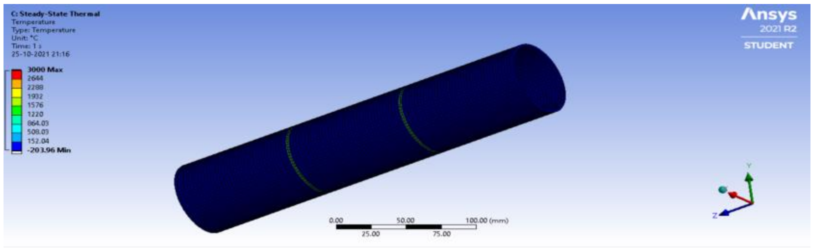

Figure 2.4: Temperature Variation on welds of modified Pipe

Temperature variation simulation were performed on the welds of the original structure (Figure 2.3) and then the modified structure (Figure 2.4). This was done in order to check the thermal behavior of 304HCu with varying dimensions. This would direct us to the point that what should be appropriate/ideal length and thickness and diameter of a pipe/pipes to work effectively.

Thermal Error

Table 2.4: Thermal Error

Minimum	**Maximum**	**Average**
1.4225 x 10^{-21}	3.2368 x 10^{-7}	1.58 x 10^{-6}

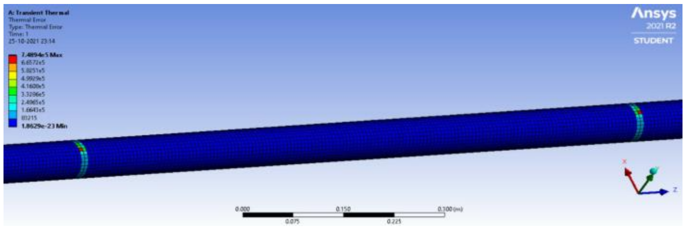

Figure 2.5: Thermal Error on welds of standard pipe

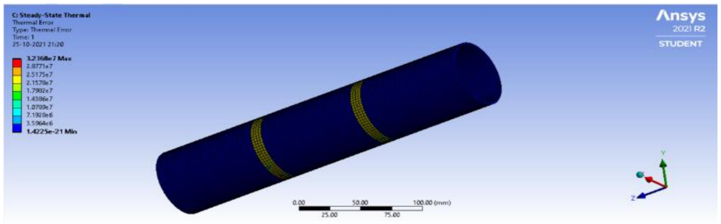

Figure 2.6: Thermal Error on welds of modified Pipe

Thermal errors are the geometric errors that a piece suffered during its manufacturing processes because of temperature changes. Temperature changes produce changes in the size of the materials.

Uniform temperature changes of the manufacturing system, accompanied by uniform temperature change of the part, would not produce change in the dimensions of the part when taken to the reference measuring temperature, provided that the machines and the part are built in the same single material. But temperature changes are never uniformly distributed along the machine and the part, and the temperature gradients can give rise to large errors in the parts produced

Directional Heat Flux

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Table 2.5: Directional Heat Flux

Minimum (W/mm^2)	**Maximum (W/mm^2)**	**Average (W/mm^2)**
-10.672	9.5271	5.1338 x 10^{-4}

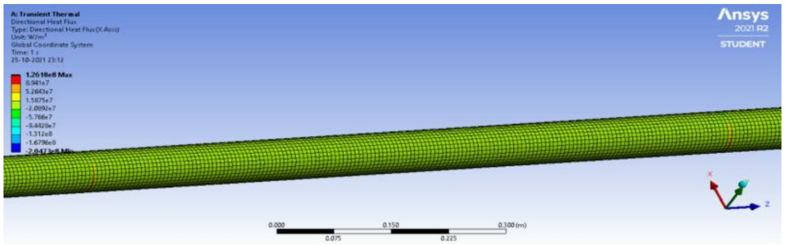

Figure 2.7: Directional Heat Flux of welds on standard pipe

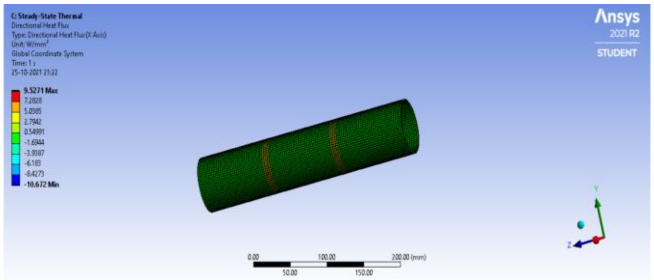

Figure 2.8: Directional Heat Flux of welds on modified pipe

Heat flux is the thermal energy transferred from one substance to another per unit time and area denoted by temperature change measured in watts per meter squared units. In simple terms, it is the heat transferred per unit area. To obtain this value, one must obtain the change in temperature, the thermal conductivity of the medium of conduction and the direction of the heat transfer. Accurate figures are obtained when the system is in a steady state condition. This knowledge helps in determining heat transfer fluids, which in turn determines the type of inhibitors and environment variables to be used and controlled to prevent corrosion.

Pulsating Current

In this process, the welds and pipe were subjected to a pulsating current source. The parameters of the pulse current, voltage and time are mentioned in Table 2. Pulsed DC (PDC) or pulsating direct current is a periodic current which changes in value but never changes direction. Some authors use the term pulsed DC to describe a signal consisting of one or more rectangular ("flat-topped"), rather than sinusoidal, pulses. Pulsed DC is commonly produced from AC (alternating current) by a half-wave rectifier or a full-wave rectifier. Full wave rectified ac is more commonly known as Rectified AC. PDC has some characteristics of both alternating current (AC) and direct current (DC) waveforms. The voltage of a DC wave is roughly constant, whereas the voltage of an AC waveform continually varies between positive and negative values. Like an AC wave, the voltage of a PDC wave continually varies, but like a DC wave, the sign of the voltage is constant.

Simulations were conducted to find out:

1. Voltage
2. Total Current Density
3. Directional Current Density
4. Total Field Intensity
5. Directional Field Intensity

Table 2.2: Process Parameters for Dynamic Wire GTAW

Parameters	Value
Pulse Current (A)	190
Base Current (A)	150
Average Current (A)	176
Pulse Time (s)	0.4
Base Time (s)	0.2
Pulse Voltage (V)	10.6
Base Voltage (V)	9.9
Average Voltage (V)	10.4

Voltage

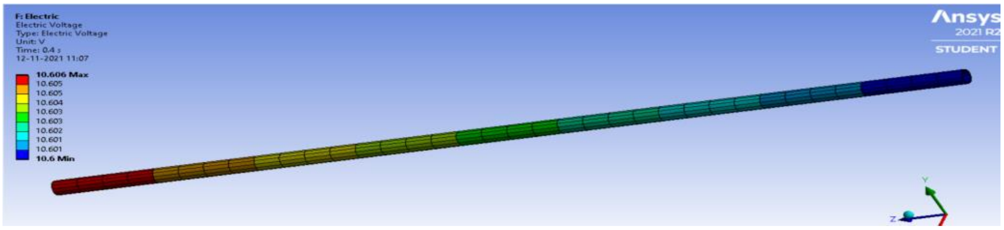

Figure 2.8: Voltage across the pipes

Table 2.6: Voltage across the pipes

Minimum (V)	Maximum (V)	Average (V)
10.6	10.606	10.603

Here we come across the general trend of voltage across the pipe made with 304HCu with original dimensions. The data entered was taken into account with table 2.2. The voltage trends as given on both the ends and then the pipes (with welds) were subjected to necessary pulsating current which resulted in the voltage trends we get as a result here.

Total Current Density and Total Field Intensity

Table 2.7: Total Current Density and Total Field Intensity

Minimum	Maximum	Average
1.4225×10^{-21}	3.2368×10^{7}	1.58×10^{6}
Minimum	**Maximum**	**Average**
1.4225×10^{-21}	3.2368×10^{7}	1.58×10^{6}

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Here we find the Total current density and total field intensity for the pipe with the original dimensions. This data gives us a rough idea of how much the pipes made with 304HCu can withstand, when if subjected to such amounts of current and voltage behaviors.

Directional Current Density

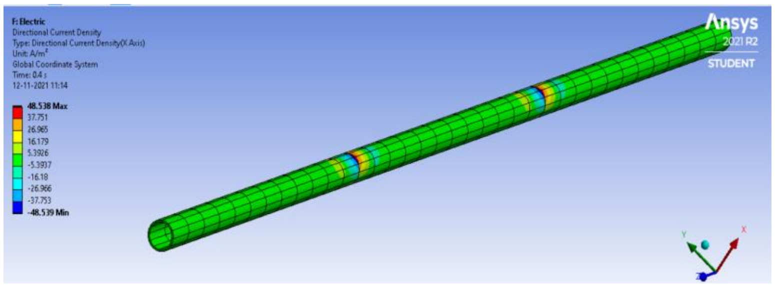

Figure 2.9: Directional Current Density

Current density is the amount of charge per unit time that flows through a unit area of a chosen cross section. The current density vector is defined as a vector whose magnitude is the electric current per cross-sectional area at a given point in space, its direction being that of the motion of the positive charges at this point. In SI base units, the electric current density is measured in amperes per square meter.

Table 2.8: Directional Current Density

Minimum (A/m^2)	**Maximum (A/m^2)**	**Average (A/m^2)**
-48.539	48.538	-1.4294×10^{-4}

2.2.3.4 Directional Field Intensity

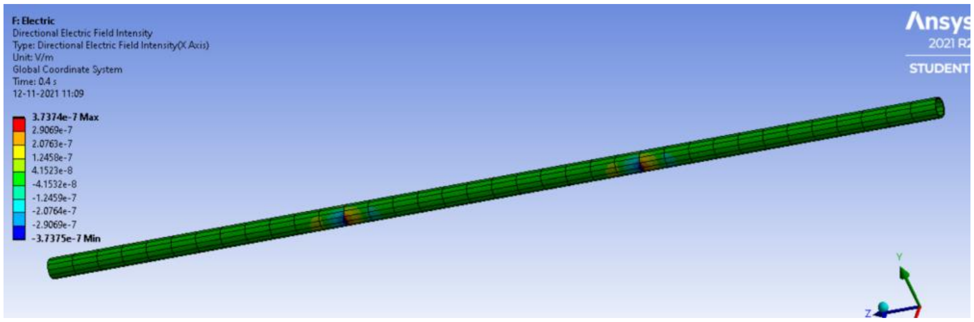

Figure 2.10: ***Directional Field Intensity***

Table 2.9: Directional Field Intensity

Minimum (V/m)	**Maximum (V/m)**	**Average (V/m)**
-3.775×10^{-7}	3.774×10^{-7}	-1.1003×10^{-12}

An electric field is defined as the space around a charge or charged body in which other charges (less in magnitude than source charge) experience an electric force. It can be further defined as the force experienced per unit test charge. It is a vector quantity and is directed away from the positive charge as well as directed towards the negative charge. The Electric fields intensities are important in many areas of physics and are exploited practically in electrical technology as well. Taking an atomic scale, we can define that the electric field is responsible for the attractive force between the atomic nucleus and electrons that hold atoms together and the forces between atoms that cause chemical bonding.

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III. COMPARISON WITH 304 SS AND CONCLUSION

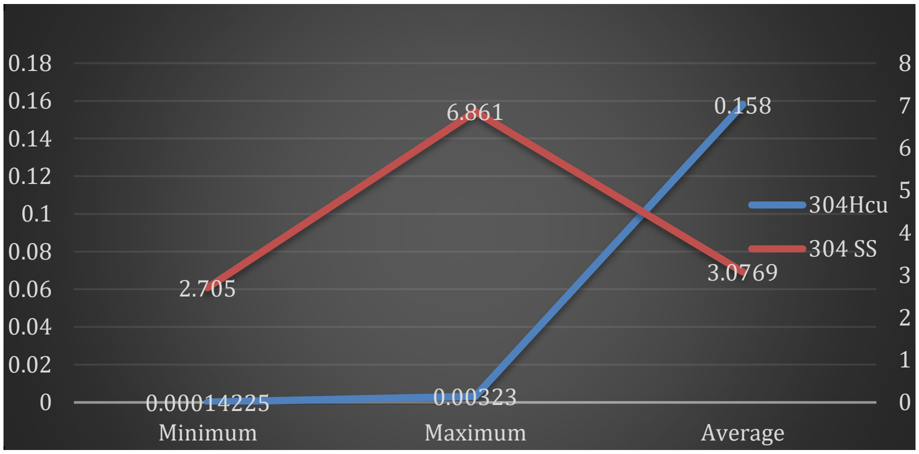

Figure 3.1: Thermal Error

Comparison of pipes made with 304HCu (Blue) vs pipes made with 304 SS(red). Here we compare the Thermal error trends in welded pipes designed with either material. Minimum takes values in the order 10^{-17}, maximum takes values in the order 10^{-5} and Average takes values in the order10^{-4}.

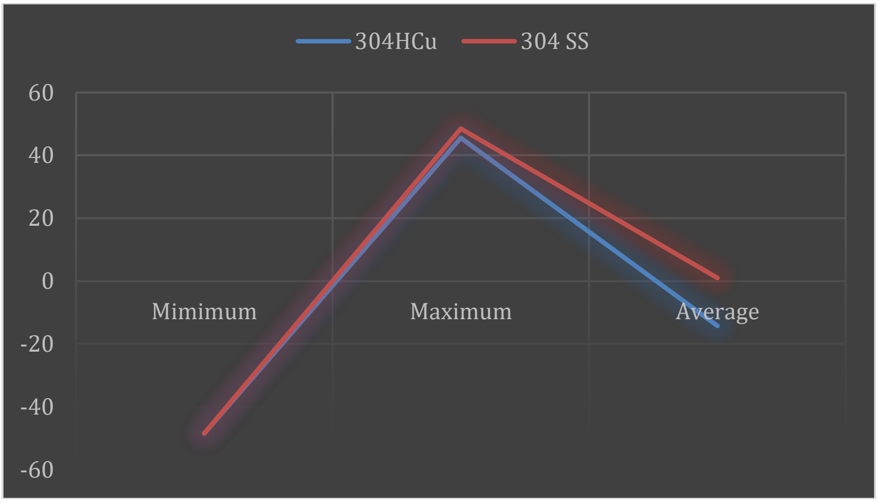

Figure 3.2: Directional Current Density

Comparison of pipes made with 304HCu (Blue) vs pipes made with 304 SS(red). Here we compare the Directional Current Density trends in welded pipes designed with either material. Average takes values in the order 10^{-4}.

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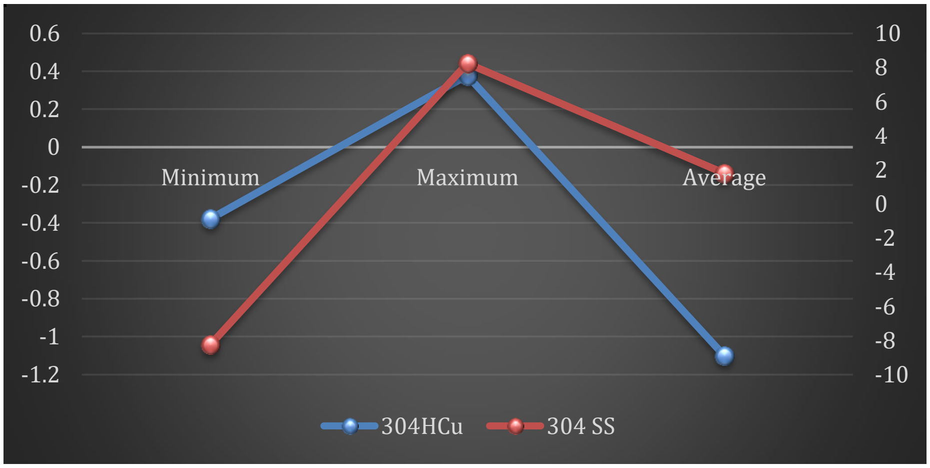

Figure 3.3: Directional Electric Field Intensity

Comparison of pipes made with 304HCu (Blue) vs pipes made with 304 SS(red). Here we compare the Directional Electric Field Intensity trends in welded pipes designed with either material. Minimum and maximum takes values in the order 10^{-7} and Average takes values in the order 10^{-12}.

Similar experiments carried out on 304 SS (Normal Grade 304 Steel) showed variations from the result of 304HCu SS. Mostly, 304HCu SS had better resistant to changing stress and strain. UTS and YS of 304 SS is 515 MPa and 205 MPa respectively which 304HCu SS comfortably cleared. With addition of Dynamic-wire GTAW it was able to withstand excessive temperature and heat fluctuations which gives it an extra edge over 304 SS.

The weld joint is considered to be one of the weakest areas in a fabricated component. Therefore, it is necessary to consider the characteristics of the weld material to avoid failures. Weldability is usually characterized by resistance to hot cracking and the mechanical properties of the weld joints. The selection of filler material becomes an important factor for good properties of the welded component. It should have a high corrosion resistance and even better mechanical properties than the base material. To avoid hot cracks in the weld metal, the processes recommended by the filler metal producers have to be observed. The material 304HCu is weldable using state-of-the-art technologies. The following fusion welding techniques are possible: metal gas-shielded welding with welding wires, welding sticks or with cored wire electrodes and metal arc welding with lime alkaline enclosed electrodes.

IV. FUTURE ENHANCEMENT

The weld joint is one of the weakest areas in a fabricated component. Therefore, it is necessary to consider the characteristics of the weld material to avoid failures. Weldability is usually characterized by resistance to hot cracking and the mechanical properties of the weld joints.

We are planning to weld the material what we have simulated with the values we got and implement it as physical experiment for future purpose.

We plan to experiment on the corrosion resistance properties of the 304HCu SS to make it more reliable for Thermal Power Plants.

To withstand the service conditions, the sensitivity of the material to oxidation on the steam-side is an important factor. As temperature increases, the oxide scale is generally formed more quickly and with a greater thickness. The higher material loss leads to reduced wall thickness and therefore, to an increase of stress, causing creep rupture. This can be compensated to a certain extent by an increased wall thickness. In addition, the oxide scale leads to an insulation of the tube material which increases the metal temperature. Increased metal temperature again may accelerate corrosion and creep rates on the flue gas side. Moreover, spalling of the thicker oxide scales can occur during service. The buildup of these scales may cause blockage at the tube bends. The resulting decrease in steam flow could create local overheating and may lead to failure. The scale might also lead to severe erosion damage in the turbine.

To get more accurate results we will be welding a greater number of pipes of different diameters and conducting CFD Simulations with hot steam to

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determine most efficient changes in material properties and dimensional aspects.

The improvement of oxidation resistance could be attributed to the fact that the shot peening process produced a surface layer of ultra-fine grains with plenty of grain boundaries, sub-grain boundaries and dislocations, which enhanced the diffusion of Cr to form a layer of high density of Cr-rich oxides on the surface.

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