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THE INFLUENCE OF DELTA FERRITE ON THE QUALITY ASSESSMENT OF AUSTENITIC STAINLESS STEEL WELDS FOR THE PRODUCTION OF OVENS

VPLIV DELTA FERITA NA KAKOVOST AVSTENITNIH NERJAVNIH ZVAROV ZA PROIZVODNJO PEČIC

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Keywords: austenitic stainless steel, delta ferrite, quality assessment, welded joints, production of ovenss

Abstract

Rust-resistant metals, such as the popular stainless steel, often contain some quantities of delta (δ) ferrite that lower the mechanical properties of welded joints. The results of the study show that the amount of δ-ferrite influences the quality assessment of austenitic stainless steel welds for the production of ovens using the resistance seam welding process.

In this article, the basic device of resistance seam welding for the production of stainless steel welds is described. The device itself will have a significant role in the operation of the line; therefore, it was very precisely constructed and designed.

Povzetek

Nerjavne kovine, kot je poznano nerjavno jeklo, pogostokrat vsebuje določene količine delta ferita (δ), ki znižuje mehanske lastnosti zvarnih spojev. Rezultati študije kažejo na to, da vsebnost delta ferita vpliva na kakovost zvarov zgrajenih iz avstenitnih nerjavnih jekel za proizvodnjo pečic z uporovnim točkovnim varilnim procesom.

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V članku je predstavljena osnovna varilna naprava za izgradnjo nerjavnih jeklenih zvarov s pomočjo točkovnega uporovnega varjenja. Naprava ima pomembno vlogo v proizvodnji liniji pečic in je zato natančno skonstruirana in oblikovana.

1 INTRODUCTION

Delta ferrite content in stainless steels is limited by international standards and is an important step in the manufacturing process of many types of industrial equipment. It is well known that the content of delta ferrite strongly affects the project's life-span prediction, hot cracking, stress corrosion cracking and solidification cracking. The expected value of ferrite content in the weld material is from 2 to 5%.

Delta ferrite microstructures in stainless steel and welded joints are determined by optical microscopy, scanning electron microscopy, X-ray diffraction, metallographic replication, vibrating sample magnetometer, as well as by the ferritoscopes, which is the most useful technique for delta ferrite measuring. Because of its portability, the equipment is simple to operate and provides a direct non-destructive response for different types of stainless steels. A standard calibration test with calibration samples made from austenitic, duplex and superduplex stainless steel should be carried out before experimental measurement with the ferritoscope. The calibration samples are correlated with the ferritoscope's magnetic response, and a specific calibration curve is configured in the equipment, *[1-4]*.

The present research work made a careful experimental analysis of the ferrite content results achieved with the ferritoscope and presents a proper selection of austenitic stainless steel for the production of ovens using the resistance seam welding process, *[7].*

2 EXPERIMENTAL PROCEDURE AND RESULTS

Delta ferrite in austenitic stainless steel welds increases resistance to stress corrosion cracking (SCC). The effect is similar to the beneficial effect of increasing ferrite phase content in duplex stainless steels. In the welds of austenitic stainless steels, *[4]*, the presence of fine, isolated pools of ferrite force the propagating crack to take a convoluted path, increasing its resistance to SCC. The effect of low-temperature thermal ageing (simulating the long-term exposure of the welds to the operating temperature of the nuclear reactors) on SCC in a high-temperature aqueous environment has suggested, *[1-3]*, that the threshold stress level for SCC initiation was lower for the austenite-to-ferrite mode of solidification weld as compared to that for the ferrite-to-the austenite solidification mode weld (for type 316L stainless steel). Since the ferrite phase solidified in the austenite-to-ferrite mode had a higher chromium content, it was suggested that it might have a higher resistance to SCC than the weld that solidified in the ferrite-to-austenite mode. The ferrite content was calibrated and measured with a Fisher device ferritoscope, as shown in Figures 1, 2, and 3.

Figure 1: *Calibrating of ferritoscope device Fisher* with calibration samples, [5]

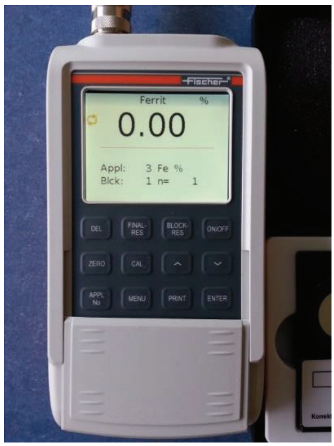

Figure 2: *Non-destructive measuring of delta ferrite content in austenitic welds with ferritoscope device Fisher,* [5]

Between the austenite and *δ*-ferrite phase fields, there is a restricted (α+γ) region that can be used to obtain two-phase or duplex structures in stainless steels. The structures are produced by having the correct balance between the *α*-forming elements (Mo, Ti, Nb, Si, and Al) and the *γ*-forming elements (Ni, Mn, C, and N). To achieve a duplex structure, it normally is necessary to increase the chromium content to above 20 wt%. However, the exact proportions of *α* and *γ* are determined by the heat treatment. It is clear from the consideration of the *γ*-loop section of the equilibrium diagram that holding in the range 1000–1300 °C will cause the ferrite content to vary over wide limits. The usual treatment is carried out between 1050 °C and 1150 °C, when the ferrite content is not sensitive to the subsequent cooling rate.

Duplex steels are stronger than the simple austenitic steels, partly as a result of the two-phase structure and also because this normally leads to a refinement of the grain size. Indeed, with suitable thermomechanical treatment between 900 °C and 1000 °C, it is possible to obtain very fine microduplex structures that can exhibit super-plasticity, i.e., very high ductilities at high temperatures, for strain rates less than a critical value. A further advantage is that duplex stainless steels are resistant to *solidification* cracking, particularly that which is associated with welding.

While the presence of δ-ferrite may have an adverse effect on corrosion resistance in some circumstances, it does improve the resistance of the steel to transgranular stress corrosion cracking as the ferrite phase is immune to this type of failure.

The super-duplex stainless steels have even better corrosion resistance than the duplex stainless steels. They are particularly superior in their resistance to localised pitting corrosion [1-4], because of their larger concentrations of chromium, molybdenum and nitrogen. To maintain the balanced ferrite/austenite microstructure, it is also necessary to boost the concentration of austenite stabilising elements, such as nickel. Super-duplex stainless steels, therefore, typically contain 27Cr-7Ni-4Mo-0.3N wt%.

Another important group of stainless steels is essentially ferritic in structure and contains between 10 and 30 wt% chromium and, by dispensing with the austenite stabilising element nickel, possesses a considerable economic advantage. These steels, particularly at the higher chromium levels, have excellent corrosion resistance in many environments and are completely free from stress corrosion. For some applications, such as the exhaust system of a car, the chromium concentration can be limited because this provides sufficient corrosion and oxidation resistance while at the same time making the alloy formable; ferrite also has a much lower thermal expansion coefficient than austenite, so that fatigue induced by temperature variation can be mitigated. The ferritic stainless steels are somewhat stronger than austenitic stainless steels, the yield stresses being in the range 300–400 MPa, but they work harden less so the tensile strengths are similar, being between 500 and 600 MPa. However, ferritic stainless steels, in general, are not as readily deep-drawn as austenitic alloys because of the overall lower ductility. However, they are suitable for other deformation processes such as spinning and cold forging, *[1-4].*

Welding causes problems due to excessive grain growth in the heat-affected zone but, recently, new low-interstitial alloys containing titanium or niobium have been shown to be readily weldable. The higher chromium ferritic alloys have excellent corrosion resistance, particularly if 1–2 wt% molybdenum is present.

Two phenomena may adversely affect the behaviour of ferritic stainless steels. First, chromium-rich ferrites when heated between 400◦C and 500◦C develop a type of embrittlement, typically known as the 475◦C embrittlement.

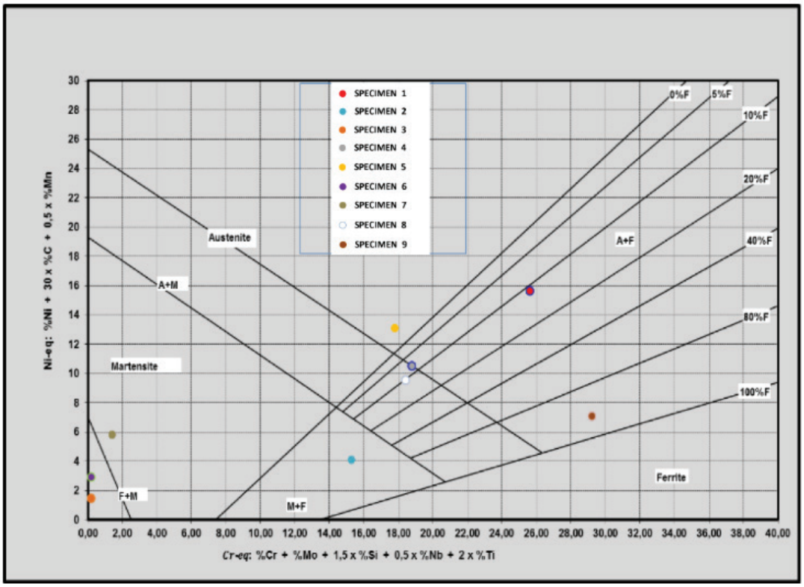

Figure 3: *Measured delta ferrite content in nine specimens of* austenitic stainless steel, *[5]*

Welding is implemented on two joints, where the plates of U-circumference and the ceiling overlap by a few millimetres, (Figure 4), *[6-7].*

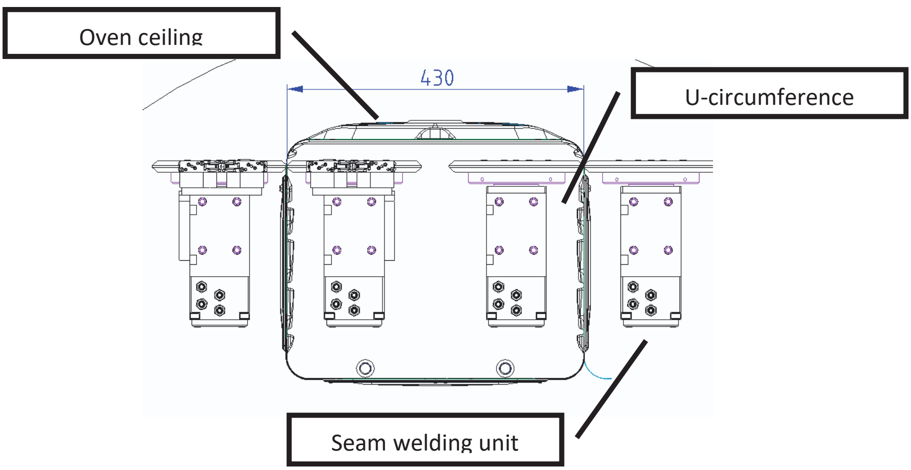

Figure 4: *Welding sketch, [7]*

Ceilings are taken from a specially modified transporter with a robot arm with a pneumatic gripper, and they are additionally positioned on a special unit in the X,Y directions.

Ceilings are then delivered to a rotatable unit, where they are positioned on lateral stands and vacuum-clamped. The U-circumference is loaded with a line manipulator (two-dimensional manipulator with several sequential grippers). The robot transfers the U-circumferences with a pneumatic gripper from a U-bending station to a line manipulator entry place (Figure 5), *[7].*

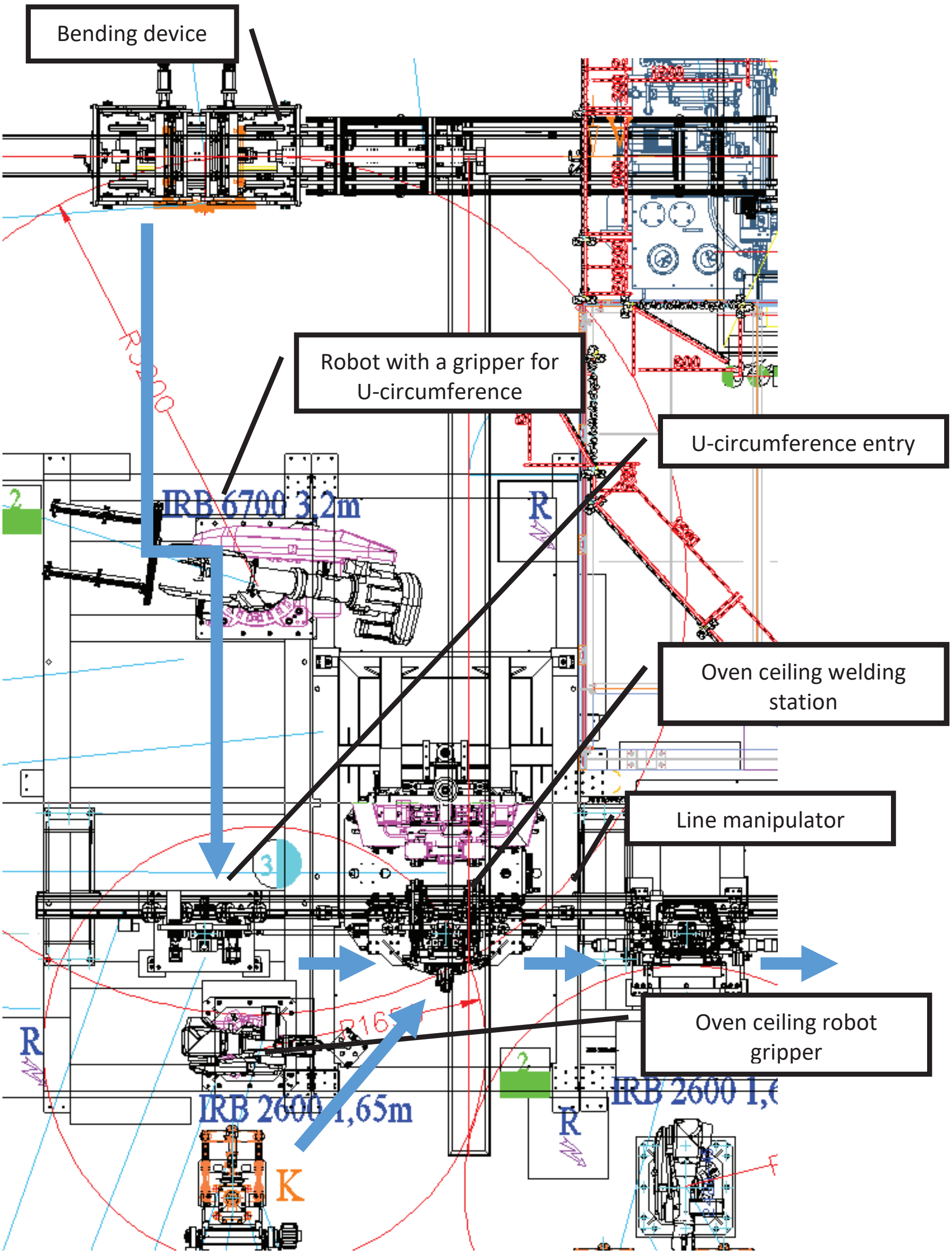

***Figure 5:** Station's ground plan [7]*

The line consists of four main connecting segments:

- U-circumference formation,
- composing and welding of the oven,
- manufacturing the oven's back end,
- transport system.

There is an unwinding station with a lifting unit for a sheet reel at the beginning of the line. After the straightening and cutting station is the station for storing cut sheets, which ensures smooth line functioning during the sheet reel exchanges.

After that, there is a station for the lubrication of cut sheets and a serving unit that transfers the sheets further in the presses, which contains hole-cutting tools, and after that on a conveyor. The U-bending station is at the end.

The robot is transmitting the U-circumference with a gripper on a composition and welding part of the line. The main feature of that part of the line is a line manipulator with 14 grippers, which are transferring ovens from one station to the other at the same time. In this part of the line, there are stations for welding and shaping different oven assembly parts. At the end of that part of the line, the carriers for enamelling are welded. At the very end of the welding line, there is a unit for the automatic assembly and welding of the oven and front end, where the robot with a pneumatic gripper is transferring the front ends from a line storage container. A set of stations for manufacturing of the back ends serves for the production of many variants of cut back ends and shapes. Back ends are delivered from line storage transporters and a robot with a pneumatic gripper on to a welding station. Custom-designed welding units are spot welding the housing of the oven with front ends, *[7].*

The station for ceiling welding (Figure 6) has the following key features:

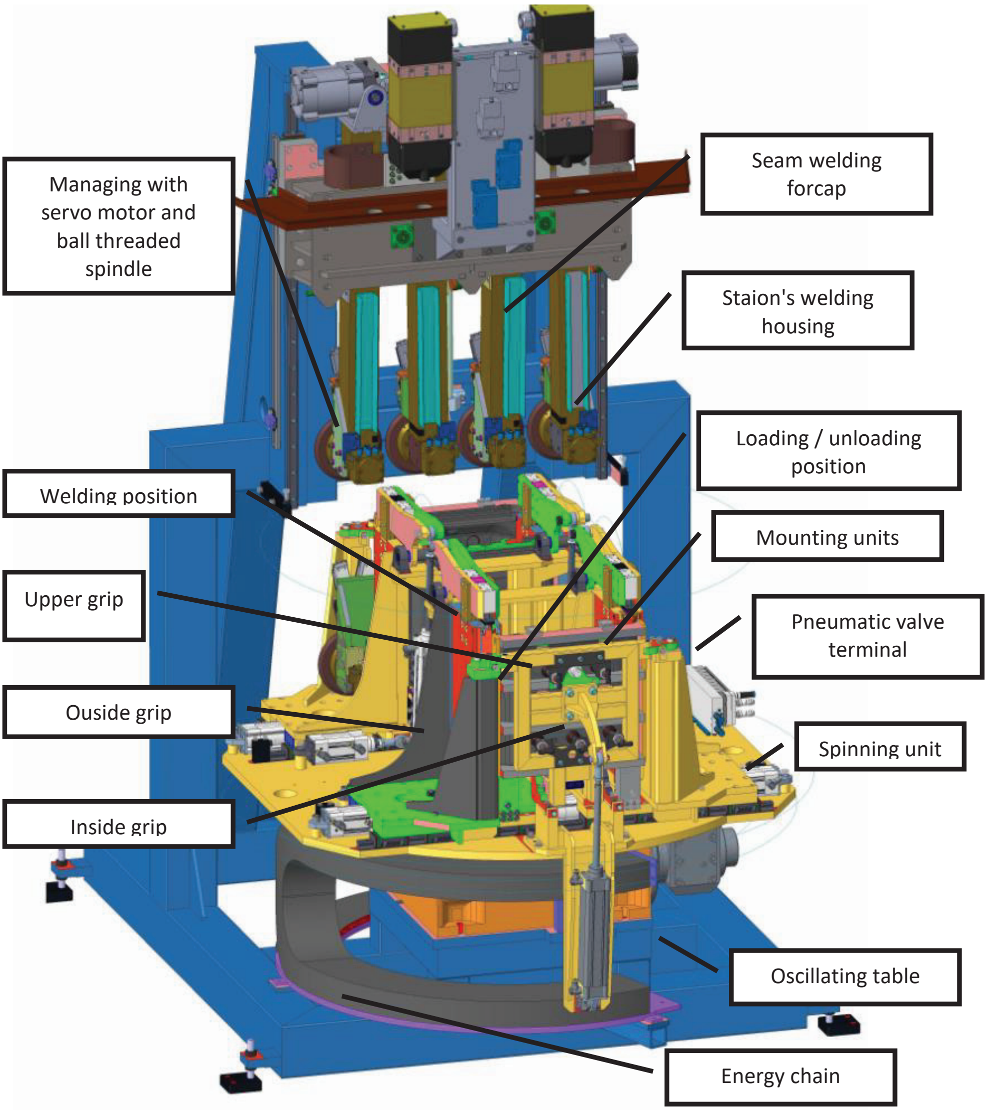

Figure 6: *Final station for oven ceiling welding, [7]*

Because of short deadlines, designing this kind of station is a process in which it is necessary to accept the decisions that affect the reliability, power consumption, welding quality, dimensions, appearance and price. All these criteria must be optimally coordinated for the success of a project. We can highlight two arguments among all the others.

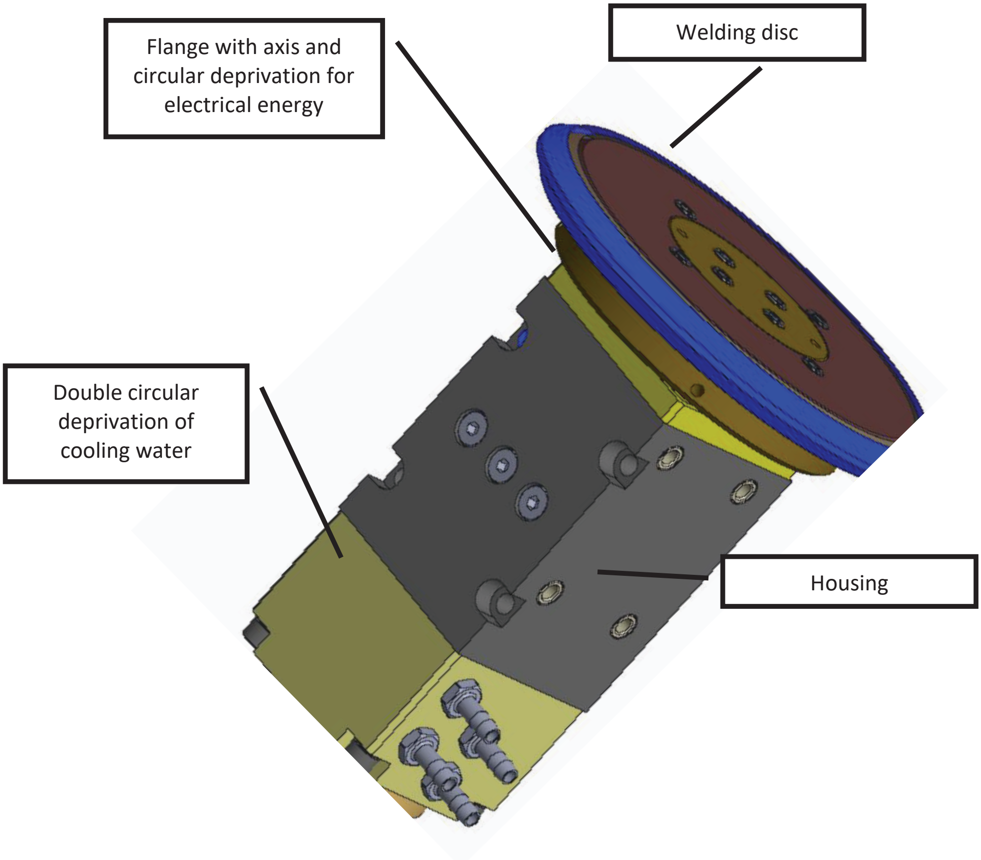

Figure 7: *Seam welding unit, [7]*

The transition of electrical energy from the frame to the rotary axis is executed with a special space that is sealed and contains a conducting material. Previously, mercury was used, but it is currently forbidden because of environmental standards. Because of welding and the enormous amount of conducting electrical energy, conduction heating occurs. Extraction of that heat is ensured with the supply of cooling water. Two units for seam welding are installed on the seam welding forceps, (Figure 7), *[6-7].*

Forceps for seam welding are vital at that station, among the correct mounting of the sheets. Actuating valves ensure the force needed for welding (Figure 8).

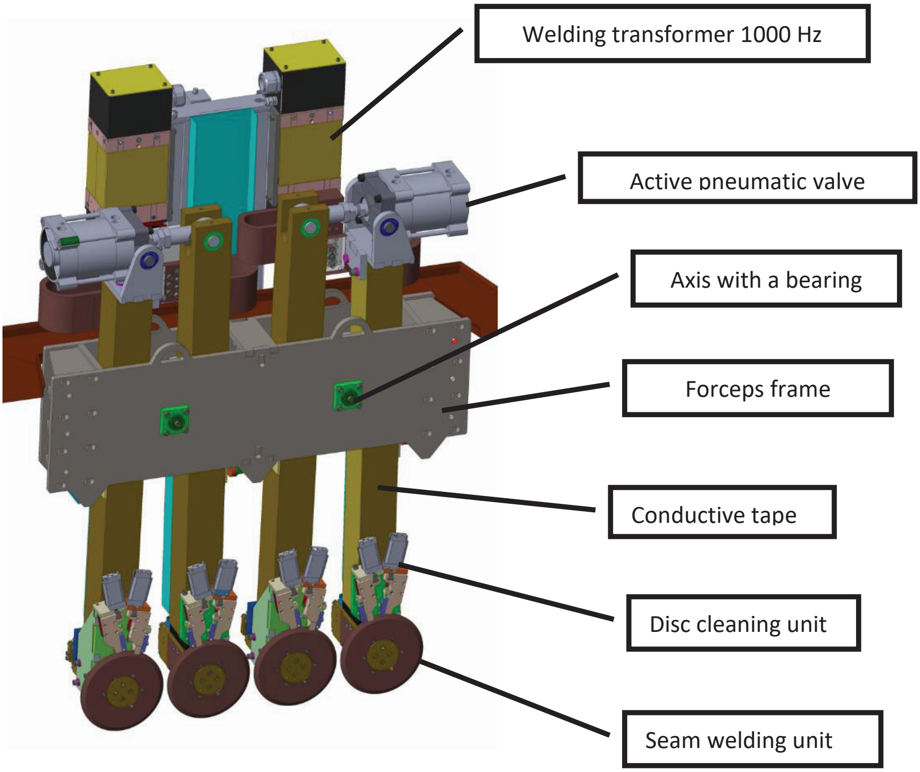

Figure 8: *Seam welding forceps, [7]*

Through tests that were made at different line and welding components, it was concluded that two seam welders were needed for each welded joint to ensure quality welding. The previous version of the station (2008) contained a seam on a straight electrode. This worked but no longer ensures sufficient quality for new demands; the sheet on the inner side was not adequately merged to the ceiling; therefore, an edge was visible. Implementing seam forceps improved the quality of the final product, *[5-10].*

The cooling is determined according to the type of weld, the number of welds per minute, the size of the current, and the cross-section of secondary conductors. Direct cooling of the tip of the electrode would be ideal, as shown in Figure 9. In that manner, a direct extraction of the heat is ensured. The life span is extended, and the welding lenses and joints are of higher quality, *[7].*

Figure 9: *The position of weld joint that prevents U-circumference and ceiling deviation, [7]*

When we are done with a weld joint, the welding disk performs a down move to a position 2 mm above the bottom edge of the oven (Figure 10). The disks must be moved as close to the edge of the oven as possible, so that the deviation of the U-circumference and the ceiling of the oven is prevented (Figure 11, Figure 12).

Figure 10: *Bottom position of seam weld, [7]*

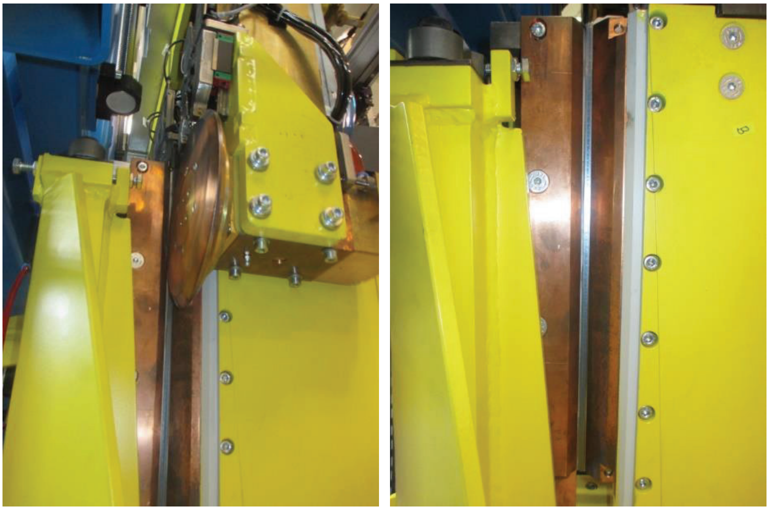

***Figure 11:** Upper position of seam weld, [7]*

***Figure 12:** An example of welded U-circumference and front end, [7]*

The BOS 6000 program is specially adapted to manage all BOSCH controllers. The program enables adapting the blocks and welding programs. In each block or program, we can set the required parameters, such as time of pre-pressing, pressing, welding, cooling, etc. Among the time parameters, the type of welding (point, seam) and the pressure of the seams to the welders can also be set.

4 CONCLUSIONS

The content of delta ferrite strongly affect the project life-span prediction, hot cracking, stress corrosion cracking and solidification cracking. The expected value of ferrite content in the weld material is from 2 to 5%.

The ferritoscope is the most useful tool for measuring delta ferrite because of its portability; the equipment is simple to operate and provides a direct non-destructive response for different types of stainless steels.

The calibration samples are correlated with ferritoscope magnetic response, and a specific calibration curve is configured in the equipment.

The current work made a careful analysis of the ferrite content results achieved by the ferritoscope and presents a proper selection of austenitic stainless steel for the production of ovens using the resistance seam welding process. The results of the study show that the amount of δ-ferrite influences the quality assessment of austenitic stainless steel welds for the production of ovens by a resistance seam welding process.

The basic device of resistance seam welding for the production of stainless steel welds is manufactured. The device itself will have a huge role in the operation of the line; therefore, it was very precisely constructed and designed.

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