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Concept of Laser Welding of Concentric Peripheral Lap Joint

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Abstract. This paper presents the concept of concentric peripheral joint. Designed concentric joint was projected to laser welding process, where using keyhole effect deep penetration trough three materials was presented. Concept of concentric joint includes using of elastic stainless steel material as an connector between two pipes. Stainless steel in form of a ring was used as an additional distance element, joined with two pipes. Presented concept was investigated using numerical simulation based on finite element method with Simufact Welding software. Performed investigation of laser welding presents possibility of using single and double beam welding. Performed simulation included a sealed joint, where only partial penetration of bottom material was obtained and full penetration joint [1]. The authors presented a comparative study of the joints using single and double laser beam welding. The welding parameters for the assumed joints were estimated via numerical simulations [2]. The study of the concentric lap joint shows the possibility of using laser beam welding in single pass welding for obtained assumed joint geometry [3].

Introduction

Transporting different kind of gas or liquid mediums require using of different type of materials. Some type of medium required stainless steels with good corrosion and chemical resistance, other material with creep resistance. Moreover, often transporting installation are operating under severe weather conditions which may required additional coating surface or some kind of covers [4,5]. Alternative approach is using concentric installation where inside pipe are made of material dedicated for transporting medium, and outside material are dedicated for weather conditions. This type of joint however required using advanced joining technology. Traditional arc welding methods indicated high temperature into elements which can lead to overheat welded materials and chance its properties [6]. Therefore, some advanced welding methods such as laser beam welding (LBW) can be used. Laser welding using keyhole effect allow to performed deep penetration in welded material in single pass and full automation of welding process [7, 8]. Moreover capillary with ionized plasma can penetrates more than one material, therefore, more advanced joint types such as lap joint can be performed [9].

When dissimilar joint are considered, differences in properties and chemical composition of welded materials must be take into account. Differences in crystallization dynamics of welded materials can affect in welding defects or damage during installation exploitation [10, 11]. In concentric joint important is to maintain constant distance between both pipes. Placing elastic connectors freely without joining with pipes effect in friction and wear of those elements, especially when material chance it's volume during heating and cooling. Joining those elements permanently can prevent it, however reduces moves of joined pipes. Therefore, important is to use

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connector made of elastic steels with good plastic deformability, such as stainless steels [12]. In transporting installations there is important to achieve sealed joints to avoid abuse flow of transported medium. In lap joints dominant force affected joint strength is shearing, therefore, increase of weld width is essential to improve joint strength. Multi beam welding system which increase spot size of beam interaction without decrease surface power density can be used for achieve this effect [13]. Concentric installation have additional advantages, over single pipe system, leakage of inside pipe not affect in leak of medium outside transporting installation.

Multiple articles consider welding of dissimilar materials, including in lap configurations, however using laser beam for welding of concentric lap joint with welding over more than two materials is new approach for projects transfer installation [14,15]. Some results of newly published studies show the application potential of special technological coatings. These coatings can be used to improve the tribological properties of materials from which conveying systems are made [5,16]. However, the coating technology has some limitations and on an industrial scale its application is difficult.

Numerical Simulation

Projecting of concentric peripheral joint was performed using numerical simulation within Simufact Welding software environment. Model consist two elements in form of pipes with wall thickness equal to 2 mm and ring connector with same thickness, which were meshed using ring mesh procedure with hexahedral type of elements [17]. Diameter of outside piper is equal to 50 mm. Finite element method (FEM) with established model was used to investigate possibility of use laser beam welding for performed concentric joint (Fig. 1).

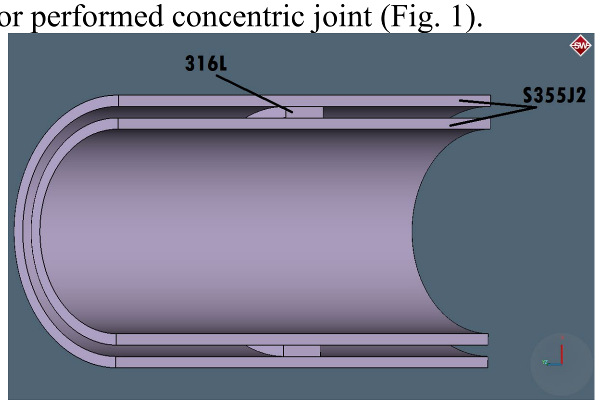

Fig. 1. *Numerical model of concentric peripheral lap joint in half view.*

Concentric joint simulation was performed in two configurations, first with joining edges of two materials and second with joining connector to both pipes. Moreover, possibility of use double beam welding optics was shown.

Heat flow in numerical simulation are based on Fourier's law. Solving the governing heat equation for three-dimensional heat conduction (1), with a partial differential equation in a nonlinear form [18], is done with the following equation:

$$\rho c(T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k(T)\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right) + q_v \quad (1)\ (1)$$

where *c(T)* - temperature-dependent specific heat capacity; *k(T)* - temperature-dependent thermal conductivity; q_v -volumetric internal energy; *x, y, z* - space coordinates; *T* - temperature; ρ - density; and *t* - time.

The conical heat source (HS) can be described as follows:

$$q_l(x,y,z) = \frac{9\eta_l P_l e^3}{\pi(e^3-1)(z_t-z_i)(r_t^2+r_t r_i+r_i^2)} \exp\left(-\frac{3[(x-vt)^2+y^2]}{\left(r_t-(r_t-r_i)\frac{z_t-z}{z_t-z_i}\right)}\right) \qquad (2)$$

where q_l - heat flux, $z_t - z_i$ - z coordinates (heat source depth), $r_t - r_i$ - upper and lower conical radius, e - natural logarithm, $r_t - (r_t - r_i)\ ((z_t - z)/(z_t - z_i))$ - linear decrease in distribution along the conical heat source, P_l - laser power, η_l - laser heat source efficiency.

Thermal conductivity, specific heat, and emissivity in the heat transfer analysis depend on the temperature, however, the used model is based on the assumption that mass density is constant [19]. Heat source efficiency was established as a 0.75. Calibration of HS was adopted for literature [20], and procedure description was presented in separate study. In case of welding using twin spot system distance between focal points was 1.4 mm.

Results

The performed thermal simulation give a results in form of temperature distribution, where shape of molten area was investigated. Results for single and double beam welding optics was presented (Fig. 2-4).

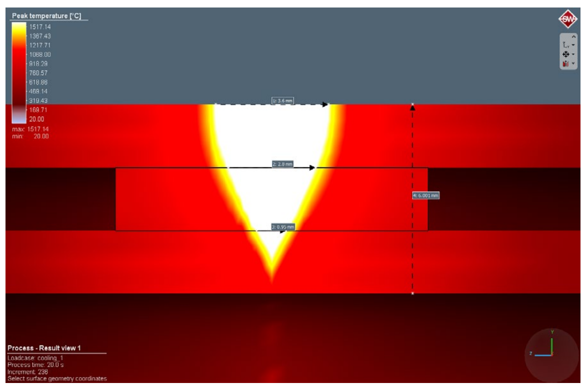

Fig. 2. *Results for single beam laser welding optics.*

Simulation shows assumed partial penetration of bottom pipe, which were achieved for laser power equal to 6 kW with welding speed 1 m/min, reducing welding velocity lead to full penetration of lower material. Width of obtained weld for surfaces of every welded materials is equal to 3.6, 2.8 and 0.95mm.

Second joint was calculated for double beam welding optics.

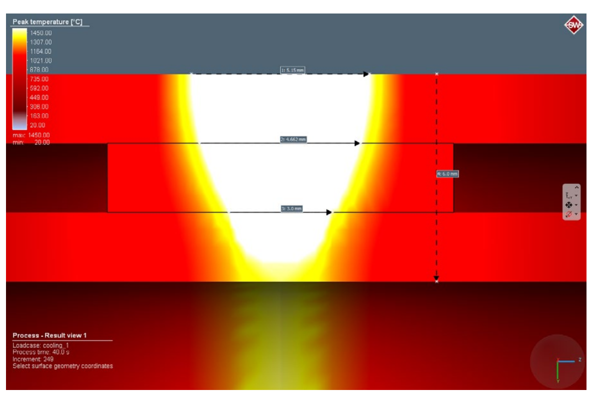

Fig. 3. *Results for double beam laser welding optics,*
with beams moving side by side.

Results also shows achieve partial penetration of bottom material, however for this welding system reduction of welding velocity was required, therefore, showed on figures 3 weld was achieved for laser power equal to 6 kW with welding speed 0.8 m/min. Calculated width is equal to 5.15, 4.66 and 3 mm respectively.

Concentric peripheral joint assume not only lap type of joint, but more complex, in form of butt-lap joint as well. In butt-lap joint two type of pipes are welded with ring connector between. While full penetration welding is not required for lap welding with connectors, quality level requirements for butt welding require complete penetration of both welded pipes [21]. For improving joint strength into projected joint double beam welding optics was considered. Comparing to previous research, full penetration was achiever reducing welding speed to 0.6 m/min (figure 4).

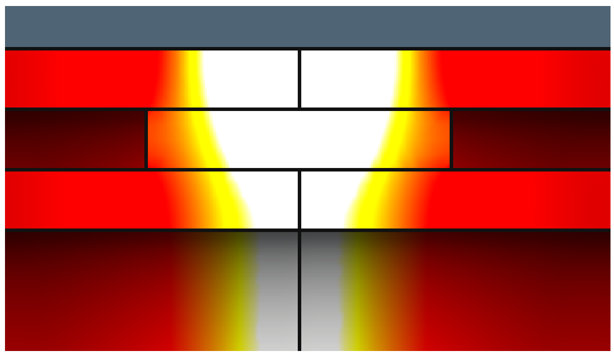

Fig. 4. *Result of full penetration concentric butt-lap joint welded using laser beam and double beam welding optics.*

Due to welding process high ratio of welded materials mixing occur, therefore, used connector have crucial role because, it's chemical composition will affect joint strength.

Summary

Authors presents concept of concentric pipe joint with inter pipes connector welded with joined pipes. Conceptualization was projected joint was investigated using numerical simulation modeling using Simufact Welding software. Established model was used for simulated single and double beam welding optics. Comparing shape and dimensions of calculated weld zone parameters for laser welding process were estimated. Partial penetration with assumed sealed joint was achieved with output power equal to 6 kW and welding speed 1 m/min for single and 0.8 m/min for double beam welding optics. For double beam welding optics full penetration was achieved with speed reduced to 0.6 m/min. Concept of projected joint was confirmed, and possibility of use double beam welding optics for improve width of weld zone was shown. Future planned research assume performing trial joints, and perform thermo-mechanic simulation method, where stress-strain analysis was planned, with additional mechanical and metallographic tests.

The presented results may be useful for researchers concerning a laser welding or a laser treatment of a surface layer [22-24] and related industry activities [25-29].

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