SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Hydrodynamic Load Effect on Composite Polymer Cold-Water Pipe Joint in Ocean Thermal Energy Conversion

Dodi Sofyan Arief[1], Basuki Wirjosentono[2,*], Jaswar Koto[3], Muhammad Dalil[4], Abdul Khair Junaidi[5]

[1] Department of Mechanical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan 20155, Indonesia
[2] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan 20155, Indonesia
[3] Department of Mechanical Engineering, Faculty of Engineering, Universitas Veteran Nasional, Jakarta, Indonesia
[4] Department of Mechanical Engineering, Faculty of Engineering, Universitas Riau, Pekanbaru, 28293, Indonesia
[5] Department of Mechanical Engineering, Sekolah Tinggi Teknologi Pekanbaru, Indonesia

ARTICLE INFO

Article history:
Received 3 October 2023
Received in revised form 20 December 2023
Accepted 31 December 2023
Available online 15 January 2024

Keywords:
Sea current; Thickness; Stress; Pipe; Joint

ABSTRACT

The cold-water pipe in Ocean Thermal Energy Conversion (OTEC) is a very important part of the process of producing electrical energy. The cold-water pipe functions to convey cold water with a temperature of 5°C from a sea depth of >500 m to the sea surface. The cold water in the pipe is allowed to experience a temperature increase of <3°C so that it can be used to dilute the ammonia in the condenser. The use of polymer composites as cold-water pipe materials is a challenge because the hydrodynamic load from seawater currents fluctuates in a direction perpendicular to the position of the pipe. The pipe length reaches >500 m consisting of several pipes connected using the Friction Stir Welding method. This research was conducted to determine the effect of the hydrodynamic load of seawater currents on Friction Stir Welding (FSW) connections, the stress distribution in pipe joints, and the thickness of pipes that are safe to use as OTEC cold water pipes. In addition, simulations were carried out using Inventor software on pipes with a length of 500 m, a diameter of 4 m, and variations in thickness from 18 cm to 30 cm which produced von Mises yield stress and stress distribution at different joints at each pipe thickness. In pipes with a thickness of less than 20 cm, the stress and stress distribution are purely influenced by the hydrodynamic load of seawater currents. Meanwhile, in pipes with a thickness greater than 24 cm, the stress that occurs in the pipe is influenced by the current and weight of the pipe. In pipes with a thickness greater than 24 cm, the stress in the pipe is concentrated in the middle of the joint which is the critical part of the pipe and is the initial point of failure. It was found that at a pipe thickness of 22 cm, the stress was distributed almost evenly because the stress caused by seawater currents was reduced by the heavy load of the pipe. So, from the simulation of cold-water pipes with polymer composite materials that experience hydrodynamic loads from seawater currents varying in thickness from 16 cm to 30 cm, it is recommended to use a pipe thickness of 22 cm so that the pipe connection is safer as an ocean-based OTEC cold water pipe application.

* *Corresponding author.*
E-mail address: basuki@usu.aca.id

https://doi.org/10.37934/arfmts.113.1.141152

1. Introduction

The world's growing energy demand for clean and sustainable power generation, as well as energy efficiency offers valuable opportunities for large-scale implementation of Ocean thermal energy conversion (OTEC) and seawater Air Conditioning (SWAC) [1,2]. Ocean Thermal Energy Conversion is a process that can produce electrical energy by using the temperature difference between warm tropical surface waters and deep cold ocean water (subsea) [3-5].

The challenge in building an OTEC power plant is the construction of cold-water pipes or the term Cold Water Pipe (CWP), which functions to drain cold water to the surface from sea depths ranging from 500-1000 m [5-12], with a pipe diameter of about > 4 m [13,14]. Pipe materials suitable for cold water pipes based on the above requirements are pipes made of thermoplastic polymer materials and polymer matrix composites because polymer materials are light and insulating. Of the various types of polymer materials, HDPE is the most appropriate to use [15,16], because HDPE is more flexible, lighter, and has lower electrical conductivity than heavier PVC and polyester materials with high conductivity even though it is flexible [17,18].

The connection of cold-water pipes is very important to obtain pipe joints that are resistant to fluctuating tensile loads due to seawater currents and produce connection characteristics/performance equal to or better than the thermoplastic polymer material and the initial polymer matrix composite. This research is focused on joining the FSW technology method for thermoplastic polymers or HDPE composites that will be applied to the OTEC industry.

Friction Stir Welding (FSW) is a solid-state joining process that uses frictional heat generated by a rotating tool to join materials. According to Pramanik *et al.,* [19] the most efficient joining method to date is the welding process, such as electric resistance welding, ultrasonic welding, hot plate welding, linear vibration welding, friction stir welding, and so on. FSW has been widely applied for joining aluminium alloys, titanium alloys, and other materials that are difficult to perform by fusion welding. Recent scientific studies suggest that FSW has the potential for the incorporation of thermoplastic polymers and polymer matrix composites [20].

The choice of polymers and polymer matrix composites has the advantages of high specific strength, good corrosion resistance, excellent design freedom, and processing ability, which provide the potential for to reduce costs and increase production efficiency with low environmental impact in the aerospace, automotive, and electronic device industries [21,22]. The polymer specialist group for the subsea sector also revealed that polymer materials enable significant cost reductions and efficient solutions for Ocean thermal energy conversion (OTEC) and seawater Air Conditioning (SWAC) technologies [23].

The European Plastic Product Manufacturer (EPPM) has produced the world's largest polymer pipe without any type of composite reinforcement with an internal diameter of 3.5 m [24]. Producing commercial polymer pipes is generally carried out by an extrusion process that produces long products. The most commonly used jointing of polymer pipes is the fusion welding process with a limited ability of a maximum pipe diameter of 1.6 m [8].

The use of large-diameter pipes is urgently needed in the OTEC industry, to produce 100 MW-net electricity, the CWP must be extended to a depth of 800 m with an internal diameter of 12 m [8,25,26]. Cost estimation studies for OTEC development state that the cost to build a CWP is around 15-20% of the total capital cost [25-27]. OTEC requires expensive capital investment and operating costs compared to other energy resources, large diameter pipelines are submerged about one mile below sea level [9]. Lockheed Martin Corporation is researching the development of CWP with a diameter of 4 m with long fibre composite HDPE materials, manufacturing is carried out by an adhesive process for joining HDPE sheets and a resin infusion moulding process for bonding HDPE sheets with long fibres [15,28].

The selection of FSW joints provides a solution for joining composite HDPE sheets having linear splice paths and joining HDPE composite pipes with rotary splice paths. The potential advantages of this welding over existing fabrication welding techniques, such as hot gas and extrusion welding, are increased productivity, particularly for thicker sections (> 10 mm; > 0.39 in); continuous welding possible; the ability to weld almost any thermoplastic; simple joint design; practically dust-free welding does not require cleaning of the joint surface; and most importantly automated processes, resulting in better quality assurance and reduced weld failures [21,29,30]. The characteristics of a good FSW process connection can be considered with three parameter categories, namely: machine parameters, welding tool parameters, and material properties by optimizing all three based on the application [31]. A limitation of the current FSW process is that it has only been proven to produce linear weld passes, and is not currently commercially available.

HDPE polymer is highly recommended for application as a CWP material in OTEC installations [13,16]. The use of short-fibre HDPE composites makes it easier for the FSW process to combine joint bonds compared to long fibres. Proposed FSW as a short fibre composite HDPE cold water pipe welding process as a development solution for pipe manufacturers and connectors with an internal diameter of > 3.5 m which is a big problem for CWP at OTEC.

In this paper, the authors aimed to utilize a general method, being able to tackle the hydrodynamic load effect on HDPE cold water pipe joints. The relative locations of cold-water pipes, the Reynolds number, and the degree of turbulence in the incoming flow are just a few of the variables that affect the hydrodynamic interaction between cold-water pipes in a uniform stream Thus, in this paper we investigate the effect of differences in pipe strength at the joints on the seawater current load that weighs on the pipe. To obtain a safe thickness of HDPE fiberglass composite pipe at the pipe joints used as ocean-based OTEC cold water pipes. Meanwhile, other dimensions of the pipe such as an inner diameter of 4 m and a pipe length of >500 m are appropriate based on the results of research on the OTEC power plant with a capacity of 100 MW [37]. Therefore, in this research, the critical issue is the pipe connection section with a pipe thickness that is safe for current loads with a maximum speed of 0.8 m/s in Indonesia [8]. The stress distribution at the pipe joint due to hydrodynamic load becomes a critical issue during operation using the Friction Stir Welding (FSW) system.

2. Research Method

2.1 Material

The method or technology known as "ocean thermal energy conversion" (OTEC) uses the temperature differentials, or "thermal gradients," between ocean surface waters and deep ocean waters to generate electricity. The material of the pipe is a polymer composite made of E-Fiberglass-reinforced High-Density Polyethylene (HDPE). In contrast to the use of steel pipe materials, it is hoped that this composite material will make the pipe corrosion resistant, require less maintenance, be lighter, not float, and have a very small temperature rise of the cold water in the pipe. This will allow the cold water flowing in a pipe longer than 500 meters to be used in the condenser to liquefy ammonia.

Cold water pipes with a length of >500 m require a connection process for installation at the OTEC factory, due to limited equipment for making pipes with a length of 500 m in one production run, and also in transportation from the fabrication location to the open sea location. Therefore, the 12 m long pipe was brought to the OTEC installation location on the high seas and the connection process was carried out using a friction welding system. so that the overall length of the pipe is 500 m.

The joining process in this research was carried out using the Friction Stir Welding method with feeding 5 mm/min and a speed of 800 rpm as shown in Figure 1.

Fig. 1. The process of welding short fiberglass-HDPE composite specimens with controlled temperature, feeding, and speed using an NC Milling machine and at the same time being formed into tensile test specimens according to ASTM D3039 to determine the mechanical properties of the joint

After making the test specimens, tensile and density tests were carried out to obtain the physical and mechanical properties of the welded and unwelded short fiberglass-HDPE composite material. Test results data are shown in Table 1.

Table 1
Density and Tensile Strength of cold-water pipe materials: short fiberglass, HDPE, Short Fiberglass-HDPE Composites, and Short Fiberglass-HDPE Composites connected with a Friction Welding system at a feeding of 5 mm/min; speed 800 rpm

Material	Density (g/cm^3)	Tensile Strength (MPa)
High-Density Polyethylene (HDPE)	0,93-0,97 (0,94)	10-60 (23,97)
Short E-Fiberglass	2,2 – 2,6 (2,58)	1400-3800
Short Fiberglass – HDPE Composite (30%-70%) weight	1,14-1,26 (1,22)	25,67-26,24 (25,94)
Short Fiberglass-HDPE Composites (30%-70%) weight: FSW (Feeding 5 mm/min, speed 800 rpm, Temperature 130^{o}C	1,14-1,26 (1,22)	24,23- 24,91 (24,52)

From Table 1, it is known that the short fiberglass-HDPE composite material that was welded with a feeding of 5 mm/min at a speed of 800 rpm experienced a decrease in tensile strength of 25.94 MPa to 24.52 MPa or a decrease of 5.47% due to the connection using friction welding.

2.2 Simulation Setup

The short fiberglass-HDPE composite material for ocean-based OTEC cold water pipes will differ in size between pipes connected by welding and without welding. To find out how much the pipe thickness changes due to a decrease in strength by welding the FSW system so that it has strength and can accept the load of seawater currents, a simulation is carried out using inventor software. The pipe length is 500 m and the diameter is 4 m and is loaded with sea water currents with input data as shown in Table 2.

Table 2
Drag force and Re for the diameter of the pipeline in 4 m [37]

Sea Current Velocity, U(m/s)	Reynolds Number, Re	Temperature (°C)	Viscosity (Pa.s)	Sea Current Density (kg/m³)	Water Depth (m)	Drag Coefficient	Drag Force (kN)
0.80	3.16E+06	21.5	1.04E-03	1024	100	0,98	75,833
0.62	2.15E+06	16.0	1.18E-03	1025	200	0,904	59,313
0.46	1.40E+06	11.0	1.35E-03	1026	300	1,07	29,435
0.35	0.971E+06	8.0	1.48E-03	1027	400	1,16	15,960
0.28	0.733E+06	6.0	1.57E-03	1027	500	1,24	7,804

The simulation is carried out by applying a current load to the pipe which has been converted into a drag force as shown in Table 2. The following formula can be used to find the present velocity that is causing the drag force on the pipe [37].

$$F_d = {}^1\!/_2\, \rho_f C_d D L U^2 \tag{1}$$

where, F_d = drag force (N), ρ_f = density (kg/m^3), C_d = drag coefficient, D = diameter of pipe (m), L = length of pipe (m), U = velocity (m/s).

In the simulation, the drag force is applied completely to the pipe with an internal diameter of 4 m and a total pipe length of 505.64 m which is composed of 12 m long pipes, and the total number of pipes becomes 42 pieces.

The bending stress that occurs in the pipe in the presence of a current load can be determined using the following Eq. (2):

$$\sigma_1, \sigma_2 = \frac{\sigma_x+\sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}^2} \tag{2}$$

The bending stress is determined by:

$$\sigma_x = -\frac{My}{I} \tag{3}$$

By integrating the force moments about the y-axis throughout the section,

$$M_y = \int z dF = \int \sigma z dA = -\frac{M}{y}\int yz dA \tag{4}$$

If the bending moment on the beam is in the plane of one of the principal axes

$$I_{xy} = \int yz dA = 0 \tag{5}$$

For the corresponding three dimensions S, the von Mises stress is equally

$$2S^2 = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \tag{6}$$

In this simulation, we only pay attention to the stress due to seawater currents, while the static compressive stress caused by seawater has no effect because the pipe is open in the sea, so the pressure inside the pipe and outside the pipe is the same. What is influential is the overall hydrostatic pressure of seawater at a depth of 500 m, which is the maximum hydrostatic pressure.

The entire pipe area is arranged with a triangular mesh of 25690 elements. as shown in Table 3. And the upper pipe (at sea level) is rigidly supported and the lower part is tied to a mooring line system.

Table 3
Details of meshing configuration

Statistics	Description
Number of Nodes	53414
Number of Elements	25690
Solution Method	Triangular Method

The simulation was run with variations in pipe thickness ranging from 14 cm to 30 cm under the pipe simulation without joints [37]. Based on the simulation, a picture of the stress contour and the magnitude of the stress in the pipe and connection parts is obtained. Therefore, it can be seen that the thickness of the pipe is safe and able to withstand a load of seawater currents, such as pipes without joints, which will be recommended for use as ocean-based OTEC cold water pipes made from HDPE fiberglass composite material that has an FSW connection system. Stress contours on the pipe will be obtained and estimates of changes in pipe thickness due to reduced strength by the FSW welding (connection) system will result in a pipe thickness that is safe to use as an OTEC cold water pipe.

3. Results and Discussion

The geometry model that has been made into a solid model is then carried out in the FEM simulation process. The results of the simulation analysis, which the Autodesk Inventor software used for the current load, are displayed as follows by entering the material attributes and data shown in Table 2. As seen in Figure 2, an overview of the entire pipe contour and the stress contour at the junction welded with the FSW system are obtained.

From Figure 2 it is known that the pipe experiences deflection due to varying currents along the pipe, and at the pipe joints, stress concentration occurs. Stress concentration occurs because the strength of the material decreases at the weld. then with materials of different strengths, a joint with a welding width of ± 2 cm, becomes the weakest part of the 500m long pipe. The simulation results are shown in red, concentrated in the Weld area.

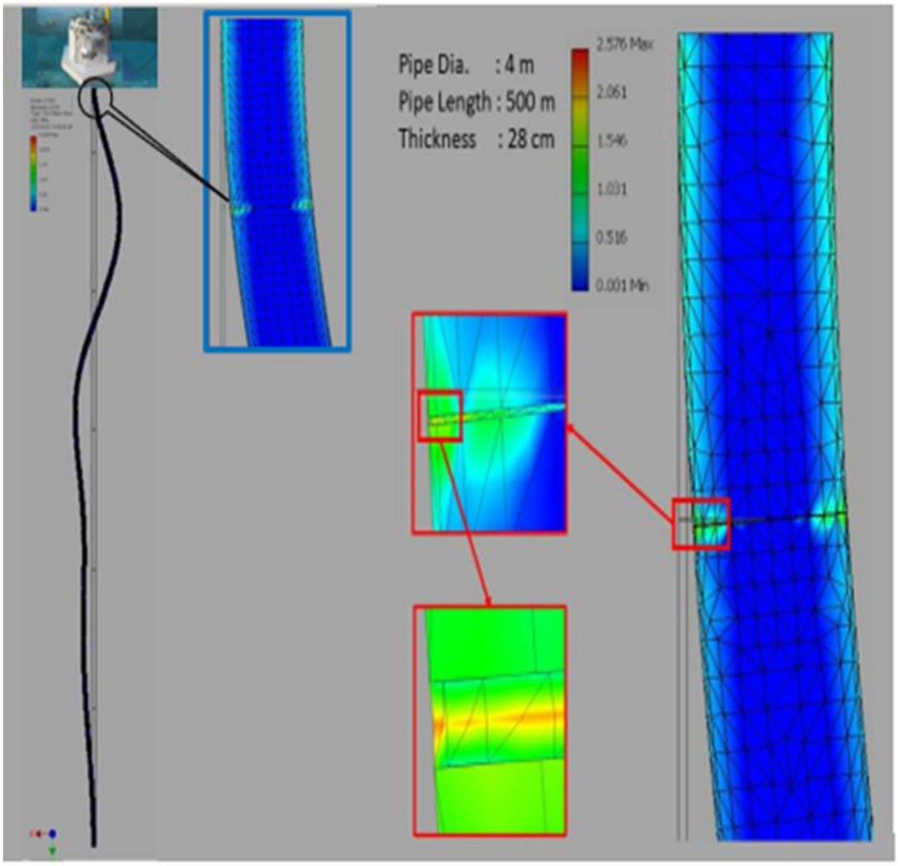
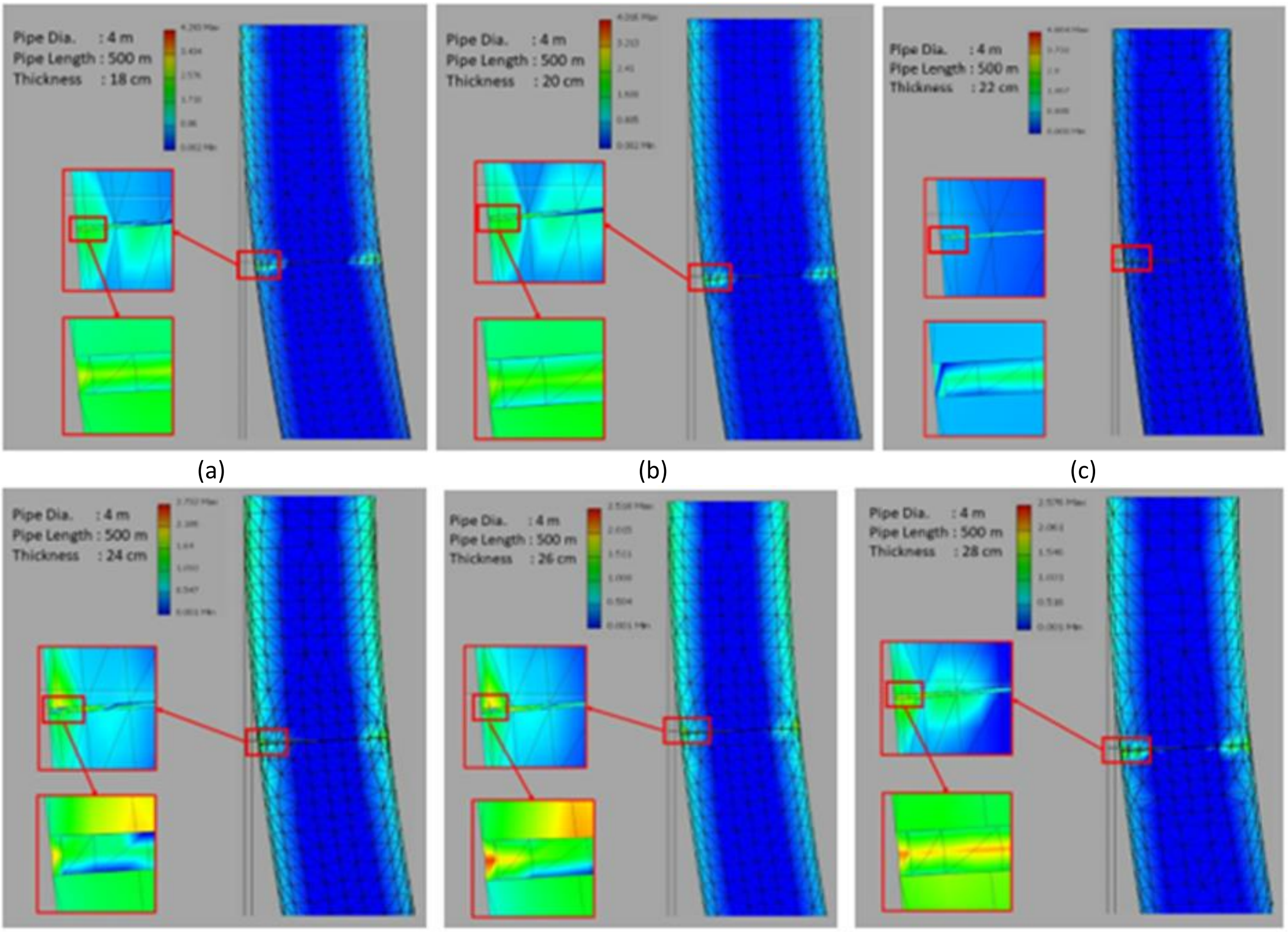


Fig. 2. Image of the contour of a pipe that is subjected to loading by sea water currents and the stress that occurs in the pipe joints welded using the Friction Stir Welding (FSW) system (thickness 28 cm)

In Figure 3, stress changes are shown in pipe thicknesses of 18 cm, 20 cm, 22 cm, 24 cm, 26 cm, and 30 cm. It is known that the stress along the pipe wall is perpendicular to the direction of the current, there is an increase in stress with greater pipe thickness. After observing the yield stress, information was obtained that the increase in stress was caused by the pipe weight increasing with increasing pipe thickness so that with increasing pipe thickness, the stress in the vertical direction or along the length of the pipe increased. The increase in voltage can also be seen from the pipe walls to the left and right of the pipe in a direction perpendicular to the direction of the current and in line with the length of the pipe, with colours ranging from blue to green and reddish. The colour change is greater with the greater the thickness of the pipe. The colour changes along the length of the pipe, which becomes longer in the direction of the pipe, occurs along the length of the pipe, this is caused by tension in the direction of the pipe or the load from the weight of the pipe. Meanwhile, the increase in stress due to perpendicular current loads will only be localized in the part of the pipe that experiences the highest deflection.

In Figure 3, it is found that the stress in the pipe is distributed throughout all parts of the pipe, or the current load and the load from the weight of the pipe are distributed over almost all parts of the pipe, namely in the pipe with a pipe thickness of 22 cm which is shown in Figure 3-(c). so that by paying attention to the stress distribution which is almost even, the stress is not concentrated to a greater extent, because the stress in the perpendicular direction is due to the load of sea water currents and in-line stress. The length of the pipe due to the weight of the pipe reduces each other, so the chance of pipe failure will be much smaller than pipes with a thicker thickness. Larger than 22 cm. So, it is recommended to use a pipe with a thickness of 22 cm so that it is safer from current loads and loads from the weight of the pipe.

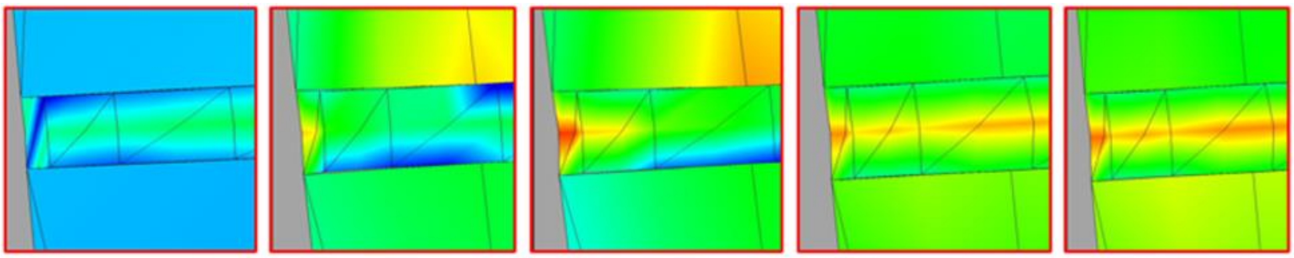


(a) (b) (c)

(d) (e) (f)

Fig. 3. Stress distribution in the HDPE-fiberglass composite pipe connection with the FSW system at a thickness of (a) 18 cm, (b) 20 cm, (c) 22 cm, (d) 24 cm, (e) 26 cm, and (f) 28 cm

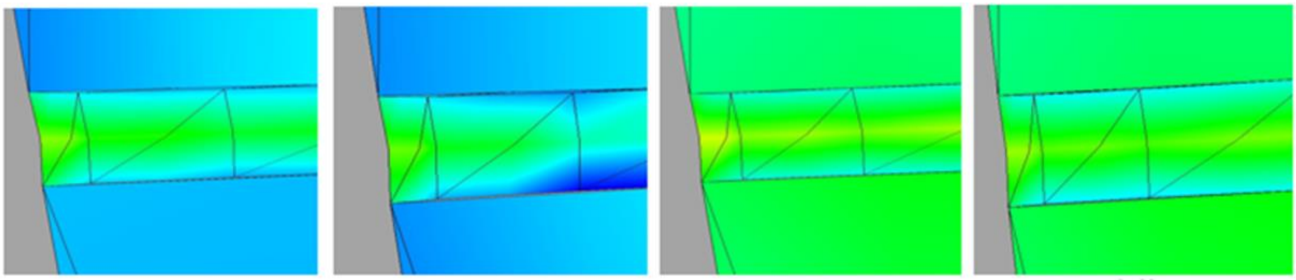
In Figure 4, it is known that the greater the thickness of the pipe, the greater the stress at the pipe joint. The stress also becomes more concentrated along the joint. Where in pipes with a thickness of 28 cm and 30 cm, the stress increases and is concentrated further along the weld. The greater the stress, the greater the failure.



(a) (b) (c) (d) (e)

Fig. 4. Stress distribution in pipe joints with a thickness of (a) 22 cm, (b) 24 cm, (c) 26 cm, (d) 28 cm, (e) 30 cm

From Figure 5(a) and (b), it is known that the stress at the connection is influenced by the current load more dominantly than the load from the weight of the pipe so that the stress is concentrated in almost all parts of the connection and Figure 5(c) and (d), the voltage has begun to be influenced by the heavy load of the pipe but is still dominant by the current load. Therefore, by paying attention to the simulation results of pipes with a thickness of 14 cm to 30 cm, the welded joint that is safer from concentrated stress is a pipe with a thickness of 22 cm.



(a) (b) (c) (d)

Fig. 5. Stress distribution in pipe joints with thickness (a) 14 cm, (b) 16 cm, (c) 18 cm and (d) 20 cm

Thicker pipes have a greater weight, with the result that the force weighing on the pipe not only increases from the drag force of seawater in the horizontal direction but also increases from the gravity of the pipe in the vertical direction down to the sea. In other words, the drag force stress is not concentrated at one point in the smaller 20 cm pipe. The gravity of the pipe overloads weak joints, especially those with a thickness of more than 22 cm, causing stress concentration at one point. The stress concentration forms a line along the joint along with the thickness of the pipe or its weight due to the effect of the force increasing vertically.

A pipe with a thickness of 22 cm is in a safe position because the combination of drag force and weight cancels each other out, so the yield stress is lower than pipes with a drag force above 20 cm and pipes with a drag force below 22 cm. This is because the pipe material at the joint is weaker than outside the joint.

Furthermore, based on the von Mises stress, which is the yield limit of the pipe material, based on the simulation results, the relationship can be described with the tensile strength and fatigue resistance limit of the HDPE composite reinforced with short fiberglass as shown in Figure 6.

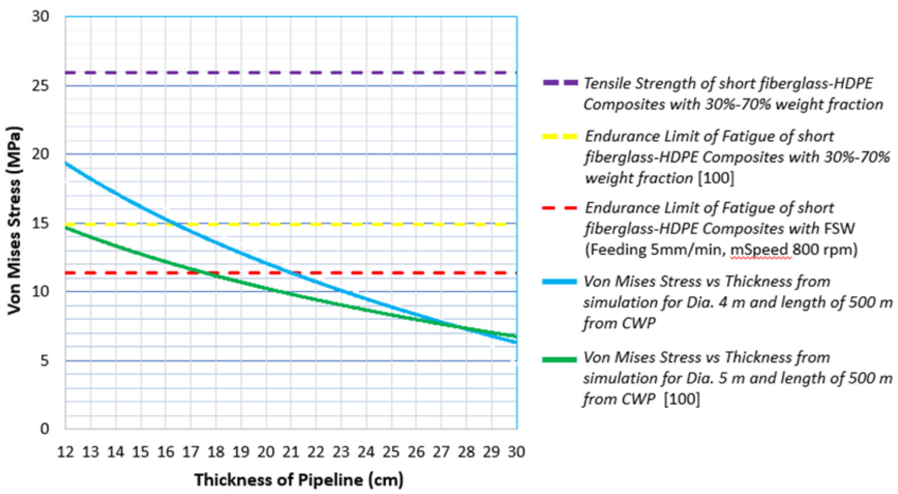


Fig. 6. Draw a curve diagram of the relationship between pipe thickness and the von Mises stress that occurs in the shot fiberglass composite pipe connection with the FSW system

From Figure 6, the relationship between the pipe's fatigue resistance limit and the pipe's von Mises stress is known. For pipes with a diameter of 4 m, without welding, the pipe can be made with a thickness of 17 cm to 30 cm, while for pipes with a diameter of 4 m with welding, the pipe can only be made with a thickness of 21 cm to 30 cm to make it safer against the burden of fluctuations in seawater currents.

The safe use of pipes not only depends on the pipe's fatigue resistance limit due to seawater currents but is also greatly influenced by the weight of the pipe. So, based on the load of seawater currents and the weight of the pipe, a pipe that is safe to make or apply as an ocean-based OTEC cold water pipe is a pipe with a thickness of 22 cm.

Furthermore, based on calculating the life of the pipe based on fatigue load, the age of the welded pipe has entered infinite life, N= 1.47 x 108 cycles. so that the welded pipe, with a thickness of 22 cm, is safe to use and has an unlimited lifespan. The possibility of failure by current loads by the heavy load of the pipe itself or by stress concentration at the connection is safe.

4. Conclusions

In this study, it can be concluded that the construction of cold-water pipes for ocean-based OTEC with FSW connections has been carried out by simulating the hydrodynamic load of seawater currents on pipes with polymer composite materials with a length of 500 m, a diameter of 4 m and with thickness variations ranging from 18 cm to 30 cm. which produces von Mises yield stress and stress distribution at different joints at each pipe thickness. In pipes with a thickness of less than 20 cm, the von Mises stress and pure stress distribution are influenced by the hydrodynamic load of seawater currents. Meanwhile, in pipes with a thickness greater than 24 cm, the stress that occurs in the pipe is influenced by the current and weight of the pipe. In pipes with a thickness greater than 24 cm, the stress in the pipe is concentrated in the middle of the joint which is the weak part of the pipe and is the initial point of failure. It was found that at a pipe thickness of 22 cm, the stress was distributed almost evenly because the stress caused by seawater currents was reduced by the heavy load of the pipe. So, from the simulation of cold-water pipes with polymer composite materials that experience hydrodynamic loads from seawater currents varying in thickness from 16 cm to 30 cm, it is recommended to use a pipe thickness of 22 cm so that the pipe connection is safer as an ocean-based OTEC cold water pipe application.

Acknowledgment
I would like to thank the Postgraduate School, Department of Mechanical Engineering, Universitas Sumatera Utara, Chemistry Postgraduate Program Faculty of Mathematics and Natural Sciences Universitas Sumatera Utara, Universitas Riau, Universiti Teknologi Malaysia, Ocean and Aerospace Research Institute (OcARI) Indonesia, for supporting and developing the study of Ocean Thermal Energy Conversion.

References
[1] Liu, Clark CK. "Ocean thermal energy conversion and open ocean mariculture: The prospect of Mainland-Taiwan collaborative research and development." *Sustainable Environment Research* 28, no. 6 (2018): 267-273. https://doi.org/10.1016/j.serj.2018.06.002

[2] Koto, J., and B. R. Negara. "Application of OTEC Overcoming Electricity-Fresh Water Crisis in Remote-Outer Islands, Indonesia." *International Journal of Environmental Research & Clean Energy* 6, no. 1 (2017): 1-9.

[3] Vega, Luis A. "Ocean thermal energy conversion." *Encyclopedia of sustainability science and technology* 6 (2012): 7296-7328. https://doi.org/10.1007/978-1-4419-0851-3_695

[4] Syamsuddin, Mega L., Adli Attamimi, Angga P. Nugraha, Syahrir Gibran, Anisah Q. Afifah, and Nindita Oriana. "OTEC potential in the Indonesian seas." *Energy Procedia* 65 (2015): 215-222. https://doi.org/10.1016/j.egypro.2015.01.028

[5] Koto, Jaswar, and Ridho Bela Negara. "Study on Ocean Thermal Energy Conversion in Morotai Island, North Maluku, Indonesia, Vol. 7." *Journal of Aeronauticalscience and engineering* (2016): 1-7.

[6] Jaswar, Koto, and Ridho Bela Negara. "Study on Ocean Thermal Energy Conversion in Seram Island, Maluku, Indonesia." *Journal of Aeronautical-science and engineering* 8 (2016): 1-7.

[7] Koto Jaswar, Ridho Bela Negara. “Preliminary Study on Ocean Thermal Energy Conversion in Siberut Island, West Sumatera, Indonesia.” *Journal of Aeronautical -science and engineering 6 (*2016): 1-7.

[8] Koto, J., and B. R. Negara. "Application of OTEC Overcoming Electricity-Fresh Water Crisis in Remote-Outer Islands, Indonesia." *International Journal of Environmental Research & Clean Energy* 6, no. 1 (2017): 1-9.

[9] Koto, Jaswar, Adek Tasri, Insannul Kamil, and Dodi Sofyan Arief. "Potential of Solar-Wind-Ocean Thermal Energy Conversion in Indonesia." *Ocean and Aerospace Research Institute, Second Edition, March* (2017).

[10] Koto, J., A. Tasri, and I. Kamil. "Sea temperature profiles for ocean thermal energy conversion (OTEC) in Siberut-Mentawai, Sumatera Barat, Indonesia." *J Subsea Offshore* 11 (2017): 10-16.

[11] Koto, Jaswar. "Potential of ocean thermal energy conversion in Indonesia." *International Journal of Environmental Research & Clean Energy* 4, no. 1 (2016): 1-7.

[12] Syamsuddin, Mega L., Adli Attamimi, Angga P. Nugraha, Syahrir Gibran, Anisah Q. Afifah, and Nindita Oriana. "OTEC potential in the Indonesian seas." *Energy Procedia* 65 (2015): 215-222. https://doi.org/10.1016/j.egypro.2015.01.028

[13] Miller, Alan, and Matthew Ascari. *OTEC advanced composite cold water pipe: Final Technical Report*. No. Final Technical Report. Lockheed Martin MS2, 2011. https://doi.org/10.2172/1024183

[14] Keesmaat, K. "Installation Limits of Large Diameter Cold Water Pipes in Deep Water for Land-Based OTEC Plants." (2015).

[15] Miller, Alan, and Matthew Ascari. *OTEC advanced composite cold water pipe: Final Technical Report*. No. Final Technical Report. Lockheed Martin MS2, 2011. https://doi.org/10.2172/1024183

[16] Mandelkern, Leo, and R. G. Alamo. "Polyethylene, linear high-density." In *Polymer data handbook*, vol. 493. New York: Oxford University Press, 1999.

[17] Mee, Y. "Shelly, Polymer data handbook." (1999).

[18] Andrady Anthony, L. "Polymer Data Handbook-Poly (vinyl chloride)." (1999).

[19] Pramanik, Alokesh, A. K. Basak, Yu Dong, P. K. Sarker, M. S. Uddin, Guy Littlefair, A. R. Dixit, and S. Chattopadhyaya. "Joining of carbon fibre reinforced polymer (CFRP) composites and aluminium alloys–A review." *Composites Part A: Applied Science and Manufacturing* 101 (2017): 1-29. https://doi.org/10.1016/j.compositesa.2017.06.007

[20] Huang, Yongxian, Xiangchen Meng, Yuming Xie, Long Wan, Zongliang Lv, Jian Cao, and Jicai Feng. "Friction stir welding/processing of polymers and polymer matrix composites." *Composites Part A: Applied Science and Manufacturing* 105 (2018): 235-257. https://doi.org/10.1016/j.compositesa.2017.12.005

[21] Strand, Seth R. *Effects of friction stir welding on polymer microstructure*. Brigham Young University, 2004.

[22] Barmouz, M., P. Shahi, and P. Asadi. "Friction stir welding/processing of polymeric materials." *Advances in friction-stir welding and processing* 14 (2014): 601-670. https://doi.org/10.1533/9780857094551.601

[23] Maeva, Aletas, Frederic Ceffis, and Pierre Guerin. "Polymer Material Qualification for OTEC/SWAC System." *Bardotgroup* (2016).

[24] Rose Brooke. “Weholite takes large diameter plastic pipes around the world.” *European Plastic Product Manufacturer (EPPM) (*2015). https://www.eppm.com/industry-news/weholite-takes-large-diameter-plastic-pipes-around-the-world

[25] Adiputra, Ristiyanto, Tomoaki Utsunomiya, Jaswar Koto, Takeshi Yasunaga, and Yasuyuki Ikegami. "Preliminary design of a 100 MW-net ocean thermal energy conversion (OTEC) power plant study case: Mentawai island, Indonesia." *Journal of Marine Science and Technology* 25 (2020): 48-68. https://doi.org/10.1007/s00773-019-00630-7

[26] Adiputra, Ristiyanto, and Tomoaki Utsunomiya. "Stability based approach to design cold-water pipe (CWP) for ocean thermal energy conversion (OTEC)." *Applied Ocean Research* 92 (2019): 101921. https://doi.org/10.1016/j.apor.2019.101921

[27] Rajasekaran, Mogheshwar Gokul, J. Koto, Dodi Sofyan Arief, M. Dalil, Muftil Badri, and B. N. Ridho. "Application of an Alternative Material to the Portland cement for the Cementing of Wellbore Top Casings of Subsea Wellhead." *Proceeding of Ocean, Mechanical and Aerospace-Science and Engineering-* 5, no. 1 (2018): 71-78.

[28] Miller, Alan, Ted Rosario, and Matt Ascari. "Selection and validation of a minimum-cost cold water pipe material, configuration, and fabrication method for ocean thermal energy conversion (OTEC) systems." *Proceedings of SAMPE* (2012): 1-28.

[29] Troughton, Michael J. *Handbook of plastics joining: a practical guide*. William Andrew, 2008.
[30] Sorensen, Carl D., Tracy W. Nelson, Seth Strand, Clark Johns, and Jason Christensen. "Joining of thermoplastics with friction stir welding." In *ANTEC 2001 conference proceedings*, p. 5. 2001.
[31] Sharma, Vipin, Ujjwal Prakash, and BV Manoj Kumar. "Surface composites by friction stir processing: A review." *Journal of Materials Processing Technology* 224 (2015): 117-134. https://doi.org/10.1016/j.jmatprotec.2015.04.019
[32] Aydin, Mustafa. "Effects of welding parameters and pre-heating on the friction stir welding of UHMW-polyethylene." *Polymer-Plastics Technology and Engineering* 49, no. 6 (2010): 595-601. https://doi.org/10.1080/03602551003664503
[33] Bozkurt, Yahya. "The optimization of friction stir welding process parameters to achieve maximum tensile strength in polyethylene sheets." *Materials & Design* 35 (2012): 440-445. https://doi.org/10.1016/j.matdes.2011.09.008
[34] Mendes, N., A. Loureiro, C. Martins, P. Neto, and J. N. Pires. "Morphology and strength of acrylonitrile butadiene styrene welds performed by robotic friction stir welding." *Materials & Design* 64 (2014): 81-90. https://doi.org/10.1016/j.matdes.2014.07.047
[35] Mendes, N., A. Loureiro, C. Martins, P. Neto, and J. N. Pires. "Effect of friction stir welding parameters on morphology and strength of acrylonitrile butadiene styrene plate welds." *Materials & Design* 58 (2014): 457-464. https://doi.org/10.1016/j.matdes.2014.02.036
[36] Jaiganesh, V., B. Maruthu, and E. Gopinath. "Optimization of process parameters on friction stir welding of high density polypropylene plate." *Procedia Engineering* 97 (2014): 1957-1965. https://doi.org/10.1016/j.proeng.2014.12.350
[37] Dalil, Muhammad, Basuki Wirjosentono, Jaswar Koto, and Dodi Sofyan Arief. "Effect of Sea Current to Composites Cold Water Pipeline of Ocean Thermal Energy Conversion in Indonesia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 107, no. 2 (2023): 27-40. https://doi.org/10.37934/arfmts.107.2.2740