Acta Polytechnica **64**(4):360–367, 2024
https://doi.org/10.14311/AP.2024.64.0360

INVESTIGATION OF THE EFFECT OF ELBOW PIPES OF TI6AL4V, 304 STAINLESS STEEL, AZ91 MATERIALS ON EROSION CORROSION BY FINITE ELEMENT ANALYSIS

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Abstract. Corrosion is the degradation of metals caused by chemical or electrochemical reactions with their environment. As a result of these reactions, undesirable conditions occur in the physical, chemical, mechanical and electrical properties of metals. These conditions cause parts made of metallic materials to become unusable. Erosion corrosion is one of the most common types of corrosion in fluid transfer. There are several methods for preventing erosion corrosion. First of all, some precautions should be taken to prevent wear. Intervention is very important in terms of cost, especially at the design stage. Measures such as wide angle bends, wall thickness of wear-resistant material and corrosion allowance can be taken, especially in applications where the flow direction needs to be changed. The aim of this study was to determine the effect of liquid fluid on erosion corrosion in Ti6Al4V, 304 stainless steel and MgAz91 elbow pipes by using the computer aided and finite element based AnsysWorkbench Explicit Dynamics module. For the design of the elbow pipe, SolidWorks was used for 3D studies. In the analysis of the pipe, the suitability of the pipe for the 3D model was examined. The effect of fluid rotation on the pipe walls and the effect of the pipe material on the flow along the pipe were determined. The standard k-e model based on the velocity-pressure relationship in continuous and steady flow was used for the flow calculations. The flow simulation showed that for all models the flow accumulation after rotation was more concentrated on the opposite walls of the pipe, as expected. The results obtained showed that the deformation in MgAZ91 material had the highest value at 9.14×10^{-8} mm. This situation has been interpreted to mean that it may vary depending on the flow rate automation. Designs on the old designs in the erosion structure of the liquid that occurs in the pipes with a new product design in the analysis design.

Keywords: Titanium, magnesium, stainless steel, erosion corrosion, FEA.

1. Introduction

Corrosion is the degradation of metals caused by chemical or electrochemical reactions with their environment. As a result of these reactions, undesirable conditions occur in the physical, chemical, mechanical and electrical properties of metals. These situations cause parts made of metallic materials to become unusable. Metal becomes high energy in the production of metallic structures. It has a strong tendency to return to its low energy state. This return to the natural state causes corrosion. Corrosion can occur locally in the form of a pit or crack, or as a general deterioration that extends over a large area [1, 2]. Oxidation of metals and alloys in a dry and gaseous environment is called chemical corrosion, whereas corrosion that occurs in an environment where there is an electron conductor to allow electron transfer between anode, cathode, electrolyte, and anode and cathode is called galvanic corrosion. Corrosion is undesirable and comes in many forms. Combined with mechanical factors, such as erosion abrasion, impact, and pitting, the economic losses caused by corrosion are very high [3, 4].

General corrosion, galvanic corrosion, erosion corrosion, cavitation corrosion, crevice corrosion, pitting corrosion, intergranular corrosion, stress corrosion, and fatigue corrosion are among the most important corrosion types [5]. Electrochemical corrosion measurements are made by Tafel Analysis, Linear Polarisation and Electrochemical Impedance Spectroscopy Techniques [6].

Pipelines, hot steam boilers, and turbine blades used to transport liquids and gases over long distances are constantly exposed to corrosion of metal surfaces by solid and liquid fluids. Even if a passive layer forms on the metal surface, the fluid will destroy this passive layer again and cause erosion of the metal surface. Pit damage (cavitation) is a special form of erosive corrosion. Cavitation involves the growth and explosion of low-pressure fluids in parts of rapidly flowing fluids near the surface. The resulting shock waves hit the surface and destroy the layer covering its surface. The released metal dissolves and corrodes. The appearance of such corroded surfaces is rough and perforated, cavities are frequent, and the surface has a honeycomb appearance [7].

Erosion corrosion is found in equipment channels used to transport gas and liquid fluids over long distances, in pipelines used to transport coal or mined ore over long distances by mixing them with water in powder form, and in hot water and steam preparation facilities [5]. In addition, the locations where the flow shrinks or changes direction, small amounts of solids and entrained states and turbulence of gas streams, pump bodies, valve seats, pipe mouths, double condensers, furnace tube inlets, parts of pipe fittings, and details of their thermals (Figure 1).

There are some studies in the literature on the corrosion damage caused by the type of elbow pipe material that carries the fluid on the inner surface of the pipe. Mansouri et al. [8] investigated the erosion damage of sand particles on different materials (13 % Cr, 25 % Cr, Inconel718). Bjordal et al. [9] investigated the erosion and corrosion properties of duplex stainless steel and WC coatings in synthetic seawater containing sand.

In such applications, different solutions can be found by predicting the corrosion caused by the fluid using computer aided simulation tools. In general, the erosion corrosion behaviour of the elbow pipe was investigated using the commercial computational fluid dynamics code FLUENT.

In this study, the effect of liquid fluid on erosion corrosion in 304 stainless steel, Ti6Al4V and MgAZ91 elbow pipes was investigated using the computer-aided finite element based AnsysWorkbench Explicit Dynamics module. Considering the elbow pipe design, the SolidWorks program was used for 3D studies. In the analysis of the pipe, it is suitable for the 3D model and evaluation is made. The changes in the amount of erosion in the pipes, which have different material structure of the liquid fluid for analysis and the changes in the design of the pipes are shown.

2. Materials and methods

2.1. Modelling and analysis

In this study, the 3D model of the elbow pipe was created using the SolidWorks program, as shown in Figure 1. Computer-aided analyses were performed using AnsysWorkbench software. The AnsysWorkbench Explicit Dynamics module was used to prepare 3D CAD models, finite element model. Loads, boundary conditions and material models are defined in AnsysWorkbench. Finite Element Analysis (FEA) is particularly important for the development of optimum machine and device designs. Additionally, it is used as a reliable technique to validate experimental or numerical results. The standard k-e model based on the velocity-pressure relationship in continuous and steady flow was used for the flow calculations [10].

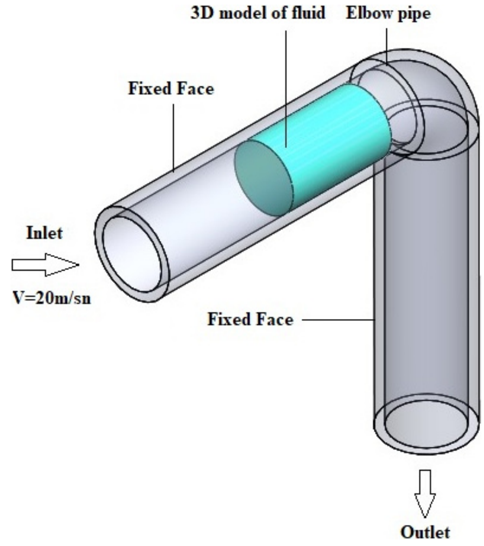


Figure 1. 3D model of the elbow pipe.

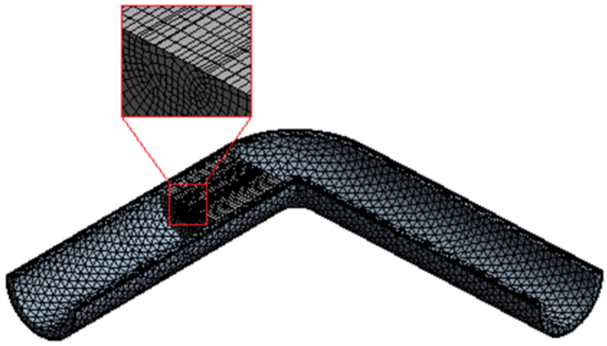


Figure 2. Mesh structure of elbow pipe and water model.

As can be seen in Figure 2, the network operation in FEA was carried out using a triangular element type for the elbow pipe and a rectangular element type for the water model. The FEA model has 22 393 nodes and 37 200 elements. The element size for the elbow pipe is set to 2 mm, while for the water model it is set to 1 mm. While the elbow is fixed from the outer surface of the pipe, the water is sent from the inlet part at a speed of $20\,\mathrm{m\,sec^{-1}}$. The properties of the 304 stainless steel, Ti6Al4V and MgAZ91 materials used as elbow pipes are given in Table 1. The contact type between the elbow pipe and the water model is chosen to be frictionless. The Steinberg Guinan Strength and Shock EOS Linear models required for the Explicit Dynamics analysis were obtained from the default values of each material in the AnsysWorkbench material library. As dynamic analyses take a long time to solve, the analysis time was set to 0.0015 seconds.

Four different finite volume analyses were performed for the elbow pipe flow model, namely 417 000, 822 000, 1 687 000 and 3 614 000. It was found that the change in the output velocity values for the last two models with the highest number of cells was below 5 %. To save analysis time and computer memory, a cell count of 1 687 000 was preferred and applied to all models.

Parameters	Ti6Al4V	MgAz91	304 SS	Water
Intensity	4 419	1 840	7 900	998
Specific H [$J\,kg^{-1}\,°C^{-1}$]	525	999	423	4 182
Shear Modulus [Pa]	4.19×10^{10}	1.67×10^{10}	7.7×10^{10}	1×10^{-6}
Thermal Conductivity [$W\,mK^{-1}$]	7.1	72.7	16.2	0.598

Table 1. Mechanical properties of materials used in FEA [10–14].

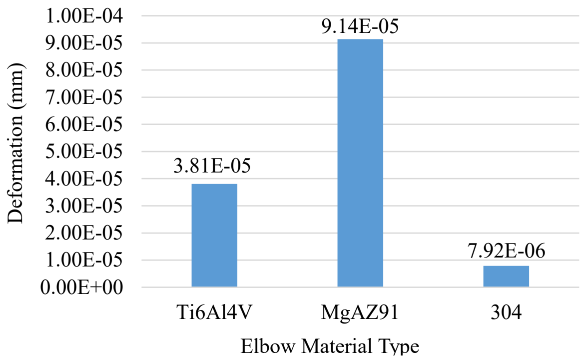


Figure 3. Deformation (erosion) values in elbow pipes.

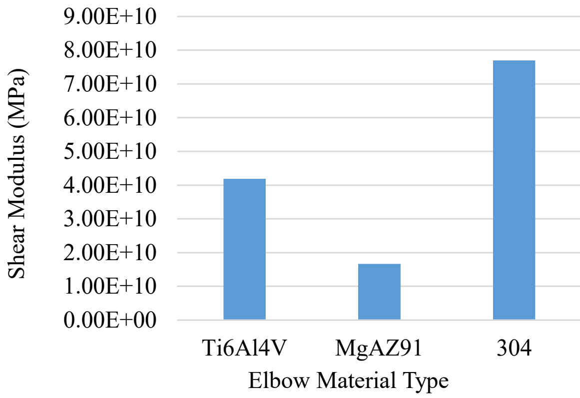


Figure 4. Shear modulus of different materials.

3. Results and discussion

As a result of the analysis, the deformation (erosion) values formed in the elbow pipes made of different materials are shown in Figure 3 and their formal views are shown in Figure 4. The deformation in the elbow pipe made of 304 stainless steel material was calculated to be 7.92×10^{-6} mm, the deformation in the elbow pipe made of Ti6Al4V material was calculated to be 3.81×10^{-5} mm, and the deformation in the elbow pipe made of MgAZ91 material was calculated to be 9.14×10^{-5} mm. This situation can be related to the shear modulus of materials as in Equation (1) and there is a relationship between shear modulus, modulus of elasticity and Poisson's ratio as in the equation. The shear modulus is related to the strength of the material such as the modulus of elasticity. As the shear modulus increases due to the modulus of elasticity, the deformation of the material will occur later. As can be seen in Figure 4, Ti6Al4V with the highest shear modulus is the material that undergoes the least deformation in Figure 5.

$$E = 2\sigma\,(1 + v)\,, \tag{1}$$

where

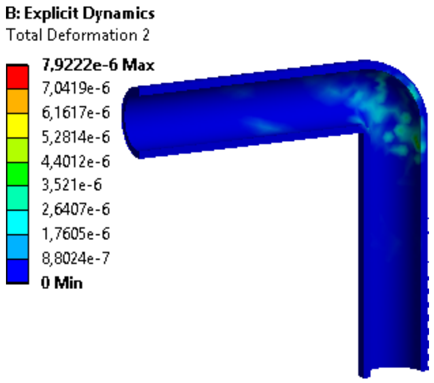
E Young module [Pa],

σ Shear module [Pa].

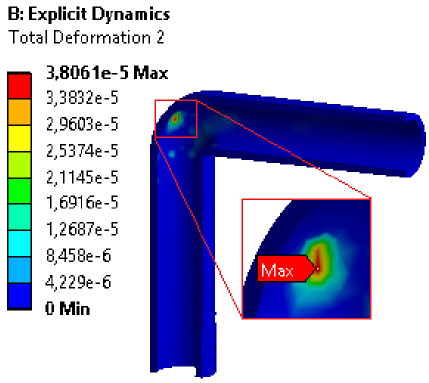
The effect of dynamic flow conditions on the elbow pipe deformations, the analysis of which was given above, was examined with SW-Flow Simulation Software. The velocity, temperature, and pressure conditions determined for the transfer of the fluid to the used parts and for the heating applications were considered together. Figure 6 shows the velocity and pressure distribution along the fluid flow, respectively. The velocity, which decreases due to negative pressure before the elbow, accelerates due to flow conditions such as the cross section narrowing after the elbow. This situation may vary depending on the initial and boundary conditions.

The variation of the inlet temperature in the range of 15–65 °C with the variation of the velocity between 10–20 $m\,s^{-1}$ in the inlet conditions has been demonstrated by parametric analyses at a static outlet pressure of 3 bar. The effect of fluid flow on the inner pipe walls is included in the analysis under different temperature and flow rate conditions. The effect on the deformation was interpreted by comparing the thermophysical properties of the solid and fluid contact surfaces. The effects of pressure and shear stress on the contact surfaces for 20 $m\,s^{-1}$ velocity and 20 °C temperature inlet condition, which are defined as standard inlet conditions, are given in Figure 7a and 7b, respectively.

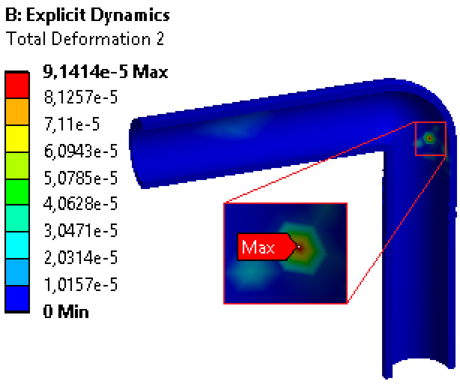
Figure 8a shows that a high inlet velocity increases the maximum pressure on the contact surfaces. However, it causes turbulent flow conditions in the elbow region. Also, the increase in the inlet temperature does not have a significant effect on the total pressure for the determined operating temperature. It is understood from the analysis that the negative pressure effect in the flow region loses its effect at inlet conditions below 14 $m\,s^{-1}$ velocity. Conversely, shear stress tends to decrease with increasing temperature. However, as can be seen in Figure 8b, the shear stress increases become more pronounced at temperatures above 45 °C, especially for high speeds. This situation is expected to reduce the deformation in the return region where the fluid comes into contact perpendicular to the surface.



(a). Ti6Al4V.

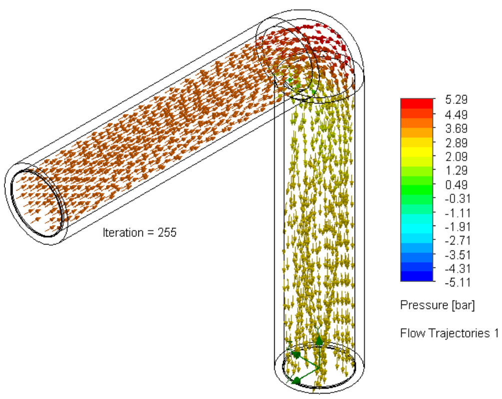


(b). MgAZ91.

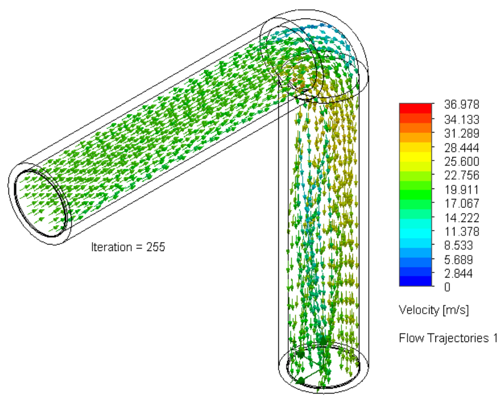


(c). 304 SS.

Figure 5. Deformation values in elbow pipes.

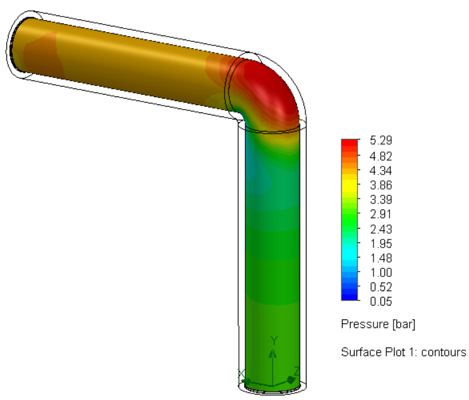


(a). Speed.

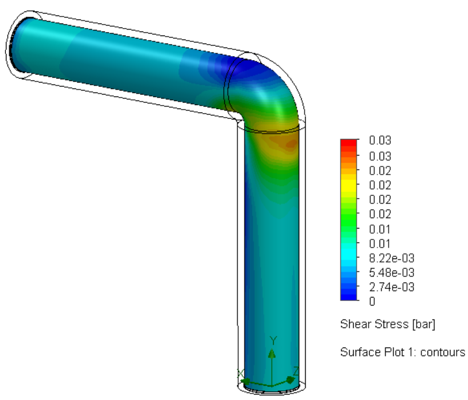


(b). Pressure.

Figure 6. Change of flow parameters.

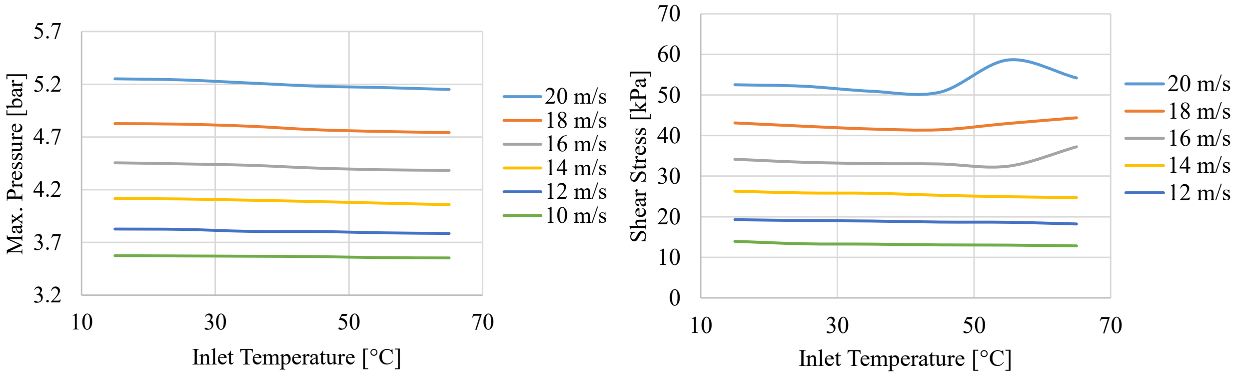


(a). Shear stress.



(b). Pressure variation.

Figure 7. Shear stress and pressure variation at the contact surface.



(a). Shear stress.

(b). Max. flow pressure.

Figure 8. Effect of velocity and temperature changes on shear stress and max. flow pressure.

In pipelines operating with heating and domestic hot water, fluid movement at an average temperature of 65 °C and its effect on solid areas are worth considering. The effect of temperature and, accordingly, thermal stresses on pipe components with pressure losses should be investigated. It is important to determine the fluid material of the elbow, which is a very frequently used pipe connection element, correctly. In most flow conditions, the pipe wall thickness is chosen to minimize deformations, taking into account the lifetime. The temperature distributions in three different materials for the elbow exposed to the same size and flow conditions are shown in Figure 9. Reference axes (OX, OY, OZ) were drawn from the elbow centre outward to determine the conditions before and after the flow change direction. Different temperature conditions emerged in solid regions. It is clear that the temperature difference in the inner and outer parts of the elbow will be responsible for deformations due to thermal stresses in long-term use.

4. Conclusion

In this computer-aided finite element-based study, erosion corrosion occurring in elbow pipes of different materials was solved by taking into account the amount of deformation caused by the liquid fluid on the elbow pipe. When the results are examined, it is found that the shear modulus of the materials have an impact on erosion corrosion. It was determined that 304 stainless steel elbow pipe, which is one of the materials used in this study, has a higher shear modulus, it has less deformation, and therefore less erosion corrosion. The lower shear modulus of MgAZ91 and Ti6V4V causes higher erosion corrosion.

In this particular research study, erosion corrosion occurring in elbow pipes was investigated using computer-aided finite element analysis. The study aimed to understand and address the issue of erosion corrosion by considering the deformation caused by the fluid flowing through the elbow pipe. By examining the obtained results, it became apparent that the shear modulus of the materials used in the pipes played a significant role in influencing erosion corrosion.

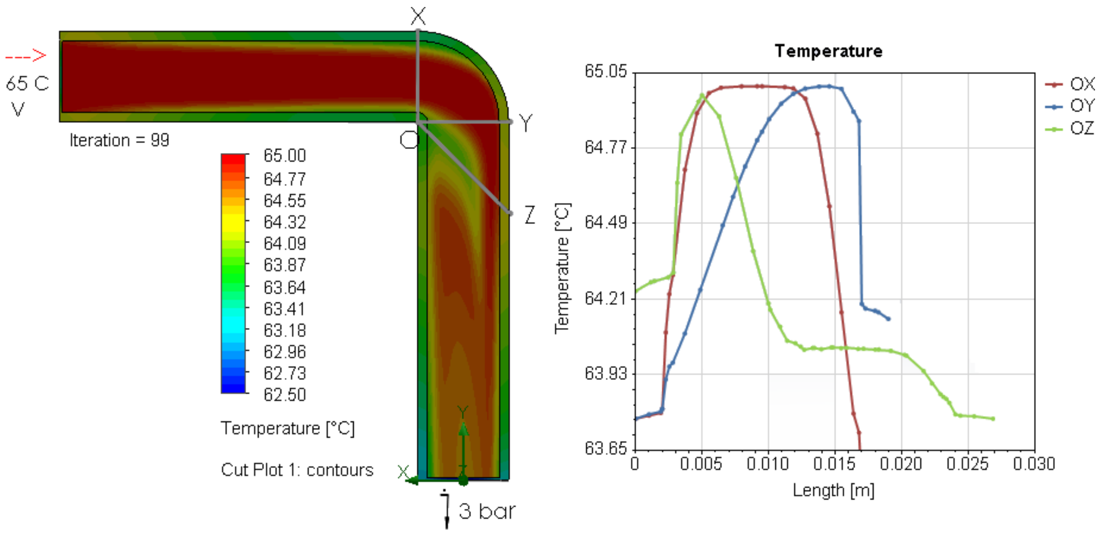
One of the materials investigated in this study was 304 stainless steel, commonly used in various industrial applications due to its excellent corrosion resistance properties. It was found that the 304 stainless steel elbow pipe exhibited a higher shear modulus compared to the other materials examined. This higher shear modulus resulted in less deformation of the elbow pipe when subjected to the fluid flow, leading to reduced erosion corrosion.

The materials MgAZ91 and Ti6V4V, which were also included in the study, displayed lower shear modulus. As a consequence, these materials experienced greater deformation when exposed to the flowing fluid, which subsequently contributed to increased erosion corrosion. The lower shear modulus of these materials made them more susceptible to the erosive forces exerted by the fluid, leading to more pronounced erosion corrosion effects.

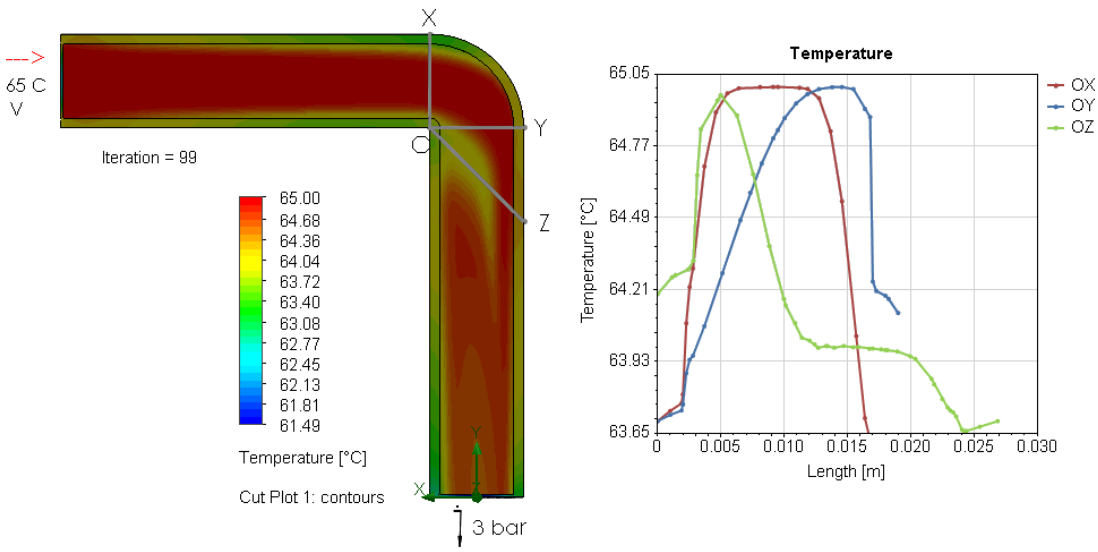
Overall, this study highlights the importance of considering material properties such as shear modulus in the context of erosion corrosion. The results indicate that materials with higher shear modulus such as 304 stainless steel tend to exhibit reduced deformation, shear modulus, and lower levels of erosion corrosion. Conversely, materials with lower shear modulus, such as MgAZ91 and Ti6V4V, are more susceptible to deformation and, therefore, experience increased erosion corrosion.

Based on the findings and conclusions drawn from this computer-aided finite element-based study on erosion corrosion in elbow pipes, several future plans and actions can be proposed to further enhance our understanding and address this issue effectively. Here are some potential future plans:

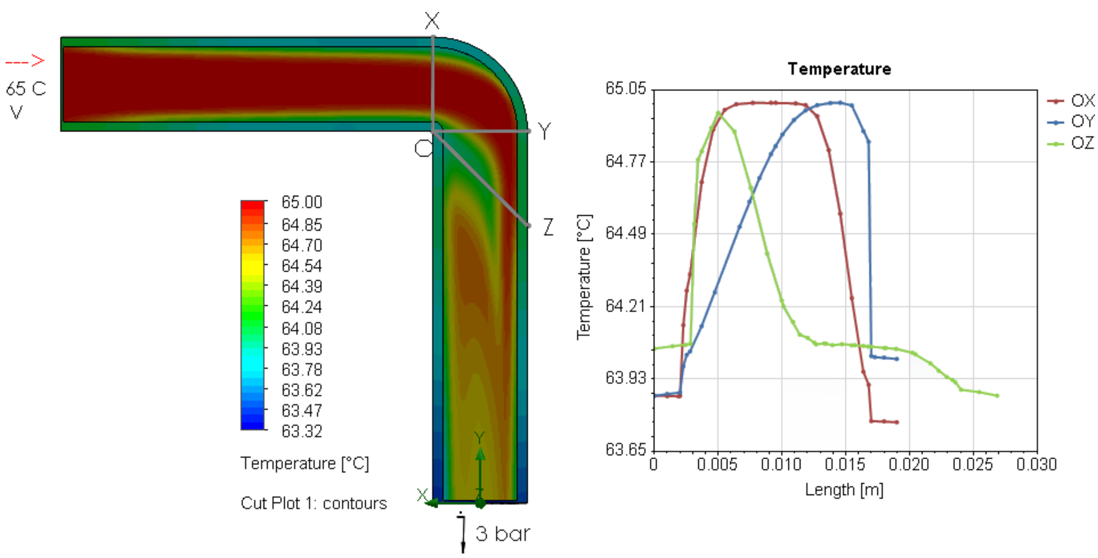
- **Material Selection and Development:** Building upon the insights gained from this study, further research can focus on identifying and developing materials with even higher shear moduli that exhibit superior resistance to erosion corrosion. This could involve exploring advanced alloys, composite materials, or coatings specifically



(a). Ti6Al4V.



(b). MgAZ91.



(c). 304 SS.

Figure 9. Effect of temperature on solid regions in elbow flow.

designed to mitigate erosion corrosion in elbow pipes.

- **Experimental Validation:** To validate the computational findings of this study, it would be valuable to conduct experimental tests on various elbow pipe materials under controlled erosion corrosion conditions. This would provide real-world data to verify the correlation between shear modulus, deformation, and erosion corrosion, thus enhancing the reliability of the study's conclusions.
- **Optimisation of Elbow Pipe Geometry:** Investigating the influence of elbow pipe geometry on erosion corrosion can be a crucial area for future research. By analysing different elbow designs, including curvature, radius, and flow patterns, it may be possible to identify geometrical configurations that minimise fluid-induced deformation and subsequent erosion corrosion.
- **Fluid Flow Analysis:** Conducting comprehensive fluid flow analysis can help to understand the impact of fluid velocities, turbulence, impurities, and other flow parameters on erosion corrosion in elbow pipes. Computational fluid dynamics (CFD) simulations can provide valuable insights into fluid behavior and its correlation with erosion corrosion, assisting in developing strategies to mitigate the problem.
- **Corrosion Protection Strategies:** Considering the specific conditions and requirements of different industries, developing tailored corrosion protection strategies for elbow pipes can be an important avenue for future work. This could involve an implementation of corrosion-resistant coatings, inhibitors, or innovative surface treatments to mitigate erosion corrosion and extend the service life of elbow pipe systems.
- **Field Studies and Monitoring:** Conducting field studies and long-term monitoring of elbow pipe systems in real-world industrial environments can provide valuable data on erosion corrosion patterns, material performance, and the effectiveness of mitigation measures. This practical knowledge can inform future research and engineering practice.
- **Design Guidelines and Standards:** Based on the accumulated knowledge and research results, the development of design guidelines and standards specific to elbow pipes can be envisaged. These guidelines would incorporate considerations for material selection, geometry optimisation, and corrosion protection strategies to ensure the longevity and reliability of elbow pipe systems in various applications.
- The results obtained showed that the deformation in the MgAZ91 material had the highest value, 9.14×10^{-8} mm. This situation has been interpreted to mean that it may vary depending on the flow rate automation.

By pursuing these future plans and conducting further research in the field of erosion corrosion in elbow pipes, we can enhance our understanding, develop improved materials and design approaches, and implement effective mitigation strategies. Ultimately, these efforts can contribute to safer, more durable, and efficient elbow pipe systems in numerous industries.

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