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The Application of Teflon Sleeves in Industrial Ball Valves

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Abstract


Given the extensive applications of ball valves in the oil, gas, and petrochemical industries, refineries, and chemical plants, primarily due to their negligible pressure drop, increasing the lifespan and operational quality of these valves is of significant importance. The most critical component of these valves is the ball, which must be manufactured with extremely high precision. Considering that the ball material in these valves is typically hardened steel with specific finishing and plating, sour gas and the passing fluid lead to corrosion and a reduction in the service life of these industrial valves. In this paper, the proposal to use a Teflon sleeve for the ball of these valves is presented. To reduce the manufacturing cost of the Teflon sleeve and prevent it from entering a plastic state, the minimum thickness of the sleeve has been determined using the Finite Element Method (FEM) within the commercial software Analysis System (ANSYS) Workbench under specific operating conditions. In this regard, although thermal properties affect the mechanical behavior of the Teflon sleeve material, this influence has been neglected. This idea will lead to an increased lifespan, a reduction in the final cost, and a decrease in the valve's weight.


Keywords: Finite element, Ball valve, Numerical simulation, Teflon sleeve.

1 | Introduction

A valve is a device used to start, stop, regulate, and control the flow of liquids or gases. Valves are divided into two major groups: domestic/building sanitary valves and industrial valves. An industrial valve is a device used to start, stop, or control the flow of fluids in pipelines, piping networks, and industrial environments. The four main functions of industrial valves can be summarized as: opening and closing the flow, controlling the flow and regulating the amount of passing fluid, preventing backflow, and controlling and regulating pressure to prevent damage to machines and equipment. Industrial valves are manufactured in various types based on their shape and the method of flow restriction. Their components and structure vary according to

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the operating temperature and pressure range, the type of fluid (gas or liquid), and the corrosiveness of the fluid. In other words, two valves within the same classification may differ in terms of physical appearance.

In addition to conventional classifications, recent hydrodynamic analyses have shown that the internal geometry of the valve has a significant impact on the flow pattern and energy loss. For instance, in control valves, phenomena such as flow separation and the formation of vortices can lead to pressure fluctuations and acoustic noise, necessitating a more precise design of internal components [1].

With the advancement of industry and the increase in valve consumption across various sectors, manufacturing plants have also multiplied. The efforts of manufacturers to enhance quality and reduce product costs have led to the design and construction of diverse types of industrial valves. Among the industrial valves whose use is particularly common in the oil, gas, and petrochemical industries, one can mention the ball valve, gate valve, globe valve, check valve, plug valve, butterfly valve, pressure-reducing valve, safety valve, and diaphragm valve.

Among the various types of industrial valves, each possessing specific advantages and disadvantages and selectable based on application requirements, industrial ball valves offer benefits that have made their use highly practical and conventional in various sectors, particularly in the oil, gas, and refinery industries, as well as in petrochemical plants and chemical factories.

The advantages of using industrial ball valves include the following:

- I. Simpler construction, lower weight, and a lower price compared to other valves.
- II. Rapid operation in opening and closing.
- III. Creation of low pressure drop.
- IV. A quarter-turn (one-to-four ratio) for opening and closing the ball port.
- V. Integration of its components and no requirement for lubrication.
- VI. Low weight, compact structure, and easy installation and operation.
- VII. Easy installation, repair, and maintenance.
- VIII. Low torque required for opening and closing (consequently resulting in easier actuator selection).
- IX. Rapid change of flow direction.
- X. Capability to use multi-port ball valves to change the flow direction.

The ball valve, gas valve, or quick-acting valve, is a simple shut-off valve that utilizes a ball-shaped closure member to stop and start the fluid flow downstream of the valve. An example of these valves is shown in *Fig. 1*.



Fig. 1. An example of an industrial ball valve and its cross-sectional view.

These closure members are typically hemispherical or spherical with a bore. By rotating the valve stem toward the open position, the ball turns, and the hole provided in its center is aligned with the fluid inlet and outlet

path; consequently, the fluid passes through the valve. When the ball rotates such that its hole is perpendicular to the fluid path, the fluid flow is stopped. Typically, the fluid entry path in ball valves is either in the form of a reduced cross-section or a full-bore path. In the first type, there is an orifice-like state where the cross-sectional area of the cavity on the sphere is smaller than the valve inlet and outlet. In the second type, the cavity on the sphere is equal to the diameter of the valve inlet and outlet. When the ball is placed in a partially open position, a turbulent flow is created in the valve; this characteristic limits the application of ball valves. Therefore, they should only be used in fully open or fully closed applications. Consequently, a ball valve can be used for flow control only when the fluid is a gas.

Numerical and experimental research has shown that the flow Coefficient (C_v) in ball valves is heavily dependent on the opening angle, and at intermediate angles, the probability of cavitation occurring increases, which can cause serious damage to the metallic surface of the ball [2]. The use of polymeric coatings can, to a large extent, dampen the destructive effects of impacts resulting from the collapse of cavitation bubbles.

The application of industrial ball valves in high temperatures and pressures, and exposure to highly corrosive materials, particularly in the oil, gas, and refinery industries, as well as in petrochemical plants and chemical factories is entirely commonplace. These types of valves are used to control many fluids, such as gases and oils. Given that ball valves are mostly placed in the path of air, gas, corrosive materials, and dry powder, and furthermore, one of the significant features of ball valves is their ability to withstand high pressures up to approximately 1000 bar, the combination of the aforementioned factors raises the need for the internal components of the valve to be resistant to operating conditions, including pressure, temperature, and corrosive materials, in order to increase the valve's lifespan.

Accordingly, such valves must have the capability to withstand the harsh operating conditions expected of them. One of the most important internal parts of a ball valve is the spherical component inside it, which is responsible for starting and stopping the flow. Sour gas and corrosive fluids passing through ball valves will cause the failure of internal components, especially the ball as the most fundamental and vital part of a ball valve, and will limit the lifespan and operational performance of these types of industrial valves, as corrosion of the ball can lead to internal leakage in the valve, which is not desirable at all. On the other hand, the high temperature and pressure of the operating environment of these valves lead to the application of substantial stresses on all internal components and parts of the valve, especially the ball; the creation of large plastic deformations resulting from these stresses (or even elastic deformations considering design tolerances) can lead to valve leakage and failure. Furthermore, the continuous starting and stopping of the flow passing through the valve (considering the high fluid pressure) can lead to cyclic loading and, consequently, fatigue of the internal components, especially the ball, which may result in valve failure [3].

In the discussion of fatigue and failure analysis, stress concentration in the connection areas between the stem and the ball, as well as the edges of the fluid flow passage, is of particular importance. The use of softer materials such as Teflon can make the contact stress distribution more uniform and prevent point stress concentrations, which are the primary factor for the initiation of fatigue cracks [4].

In this study, the feasibility of placing a Teflon sleeve [5] on the ball of industrial ball valves has been investigated using the Finite Element Method (FEM) [6] and commercial Analysis System (ANSYS) Workbench software under specified operating conditions. In this evaluation, although thermal properties affect the mechanical behavior of the Teflon sleeve material, this influence has been neglected.

examined the tensile behavior of Polytetrafluoroethylene (PTFE) under various strain rates using non-contact extensometry to accurately capture large deformations. They developed a simple yet effective constitutive model that successfully predicted strain-rate-dependent stress-strain curves with good agreement to experiments [7]. experimentally investigated the compressive behavior of PTFE over a wide range of strain rates (10^{-2}s^{-1}). Their results showed that the yield strength increases bilinearly with the logarithm of strain rate, while the yield strain decreases as strain rate increases. A modified constitutive model based on Nunes' formulation was proposed and demonstrated good agreement with experimental data up to 40% strain [8].

2 | Teflon Sleeves in Industrial Ball Valves

Selecting appropriate materials for the construction of industrial ball valve components, such that they are capable of withstanding the expected operating conditions, is of paramount importance. Depending on the application, the materials used in valve manufacturing vary. In industrial operations such as power plants, petrochemical factories, refineries, shipbuilding, and the pharmaceutical and food industries—depending on the type of fluid passing through the valve or the environment in which the valve is situated—the body and other components are constructed from carbon steel, alloy steel, or stainless steel. The most critical part of these types of valves is the ball, which must be manufactured with extremely high precision. Typically, the material of the ball in these valves consists of hardened steel with specific finishing and plating.

One of the methods that can be employed in the industry to increase the lifespan of ball valves is the use of a Teflon coating on the ball inside the valve to enhance its resistance against corrosion and the applied stresses resulting from high operating pressures. Utilizing a Teflon sleeve for the ball of these types of valves will lead to a reduction in the final cost as well as a decrease in weight.

Teflon is a fluorocarbon-based polymer discovered in 1938 by Dr. Plunkett of the DuPont Company [9]. This material was registered in 1941, and three years later, the name Teflon was trademarked by DuPont. Polytetrafluoroethylene, commonly abbreviated as PTFE, belongs to the fluoroplastic family, characterized by high chemical resistance, a wide thermal range, low friction and wear, and thermal and electrical insulation. Its major advantages are its non-stick properties and non-reactivity. Its chemical structure consists of carbon atom chains bonded together with fluorine atom branches attached to them.

Its low and near-zero coefficient of friction, combined with its solid state, has not only made it suitable for cookware but has also led to its extensive application as a sealing material in various industries. One of the applications that gives Teflon priority over other materials for use in seals and valves is its resistance to chemical attack and high temperatures; this is because seals must maintain the necessary conditions for chemical resistance at all times to prevent leakage. Teflon is a polymer whose resistance to corrosion against all industrial acids including hydrochloric acid, nitric acid, and sulfurous compounds such as sulfuric acid and sulfurous acid at various concentrations along with a coefficient of friction near zero (0.05–0.1), a melting point of 327°C, and low density, distinguishes it from other seals such as silicon carbide, tungsten carbide, and others. Furthermore, ball corrosion caused by the passage of sour gas is completely eliminated. The most important physical Properties of Teflon (PTFE) are presented in *Table 1*.

Table 1. The most important physical PTFE [10].

Property	Unit	Value
Density	g/cm ³	2.2
Melting point	°C	327
Young's modulus	GPa	0.5
Coefficient of Friction	--	0.05 – 0.1
Thermal expansion	K ⁻¹	135*10 ⁻⁶
Dielectric strength (1 MHz)	MV/m	60

Some of the physical disadvantages of Teflon include its high sensitivity to temperature changes and its low resistance to stress relaxation and the occurrence of creep. These physical properties can be improved, and specific physical characteristics can be created, by adding filler materials or by modifying its production process [8], [10], [11].

Tribological studies show that adding composites such as carbon fiber, bronze, or glass fiber to the PTFE matrix can significantly reduce the wear rate and improve resistance to creep (cold flow), without exerting a

substantial negative impact on its low coefficient of friction [12]. These structural modifications are vital for industrial valve applications at high pressures.

3 | Simulation of the Ball Valve with Teflon Sleeve

In this section, an industrial ball valve is selected, modeled, and simulated using the FEM via ANSYS Workbench software. Utilizing the simulation results, the ball sleeve of the aforementioned valve is designed within the intended operational range based on the maximum Von Mises stress criterion. The trend of the sleeve's safety factor variation in relation to sleeve thickness under various applied pressures will be presented. Finally, to evaluate the accuracy of the results provided, the mesh independence of the equivalent Von Mises stress relative to the number of elements will be investigated.

3.1 | Mechanical Specifications of the Ball Valve Components

To input data into this section, the properties of the materials used in the ball valve are presented. The elastic properties of the materials used are provided in *Table 2*, and the plastic stress-strain data for the material used in the ball sleeve is presented in *Table 3*.

Table 2. Elastic properties of the materials used in the ball valve [3], [10].

Component	Material Name	Density (kg/m ³)	Young's Modulus	Poisson's Ratio
Ball sleeve	Teflon (PTFE)	2160	482 MPa	0.45
Ball and valve body	Steel (ST37)	7800	211 GPa	0.3

Table 3. Plastic stress-strain data for the materials used in the ball valve.

Stress (MPa)	Strain (m/m)	Stress (MPa)	Strain (m/m)
2.77	0.00256	16.4	0.0966
4.35	0.00471	19.2	0.139
7.98	0.0142	22.4	0.192
10.4	0.0268	24	0.221
14.6	0.0727	25.3	0.242

The non-linear behavior of the PTFE material, as evidenced in the table above, stems from the viscoelastic-viscoelastic nature of polymers. In more precise numerical analyses, the use of hyperplastic material models such as the Mooney-Rivlin or Ogden models can provide more accurate predictions of material behavior at very large strains; however, the multilinear isotropic hardening plasticity model used here is an acceptable approximation for the limited strains encountered in industrial applications [13].

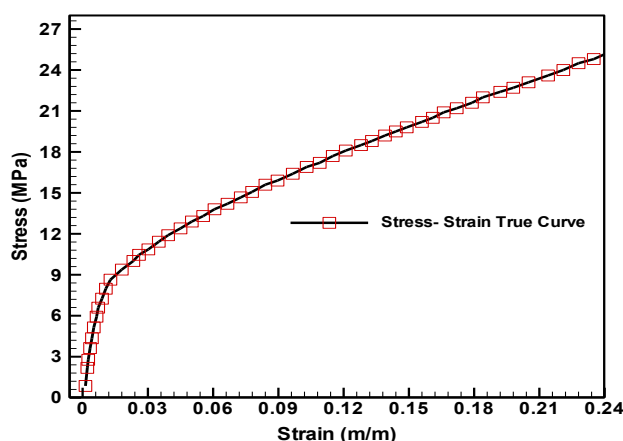


Fig. 2. True stress-strain curve of the Teflon sleeve material at a temperature of 27°C and a strain rate of 10^{-4} [2].

3.2 | Modeling of the Ball Valve with Teflon Sleeve

In this section, a ball valve has been modeled according to the API 6D design standard, with a size of 16 inches (DN= 400 mm) and model VW1.

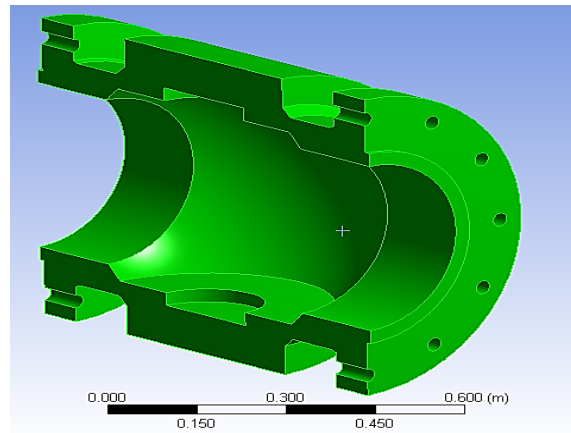


Fig. 3. 3D model of the ball valve body.

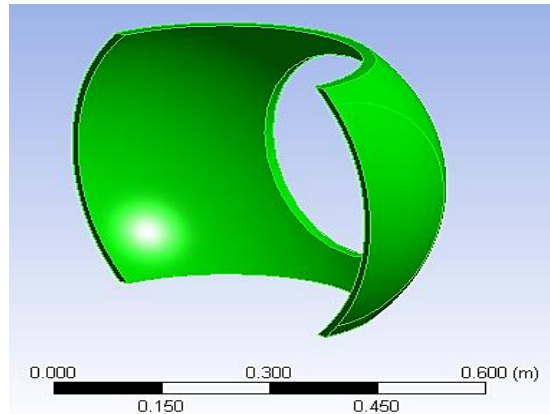


Fig. 4. 3D model of the valve ball.

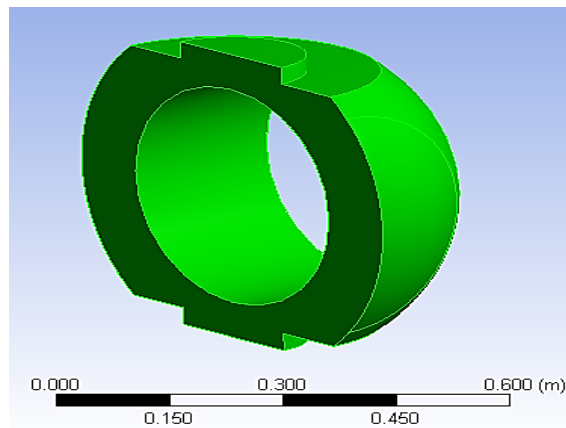


Fig. 5. 3D model of the sleeve on the valve ball.

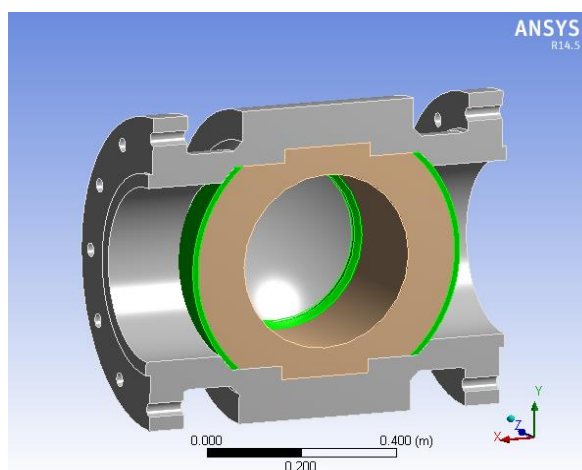


Fig. 6. 3D model of the assembled ball valve.

3.3 | Simulation of the Ball Valve with Teflon Sleeve

This section presents the meshing method and the governing boundary conditions of the problem. For the simulation, Solid 187 elements were utilized, with a total of 72,976 elements and 121,326 nodes. *Figs. 7 and 8* illustrate the meshing approach and the Solid 187 element type, respectively. Due to symmetry, only half of the valve was modeled and simulated.

Fig. 9 demonstrates the application of the symmetry boundary condition. The valve is fully constrained (zero degrees of freedom) at the flange area, and a fluid pressure of 800 psi is applied to a portion of the sleeve and the internal body of the valve. The boundary conditions applied to the ball valve are displayed in *Fig. 10*.

For the accurate simulation of the interaction between the Teflon sleeve and the metallic core of the ball, the correct definition of the Contact Mechanics is essential. In this analysis, a frictional contact model is utilized with a coefficient of friction corresponding to *Table 1*. Solution algorithms such as augmented lagrangian or pure penalty are typically recommended for better convergence in contact problems involving large deformations to prevent unphysical penetration of mesh nodes into one another [14].

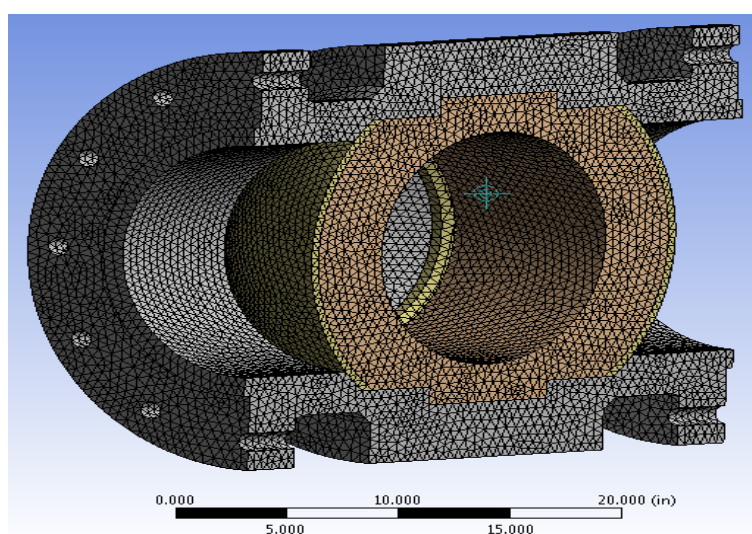


Fig. 7. Sample meshing of different ball valve components.

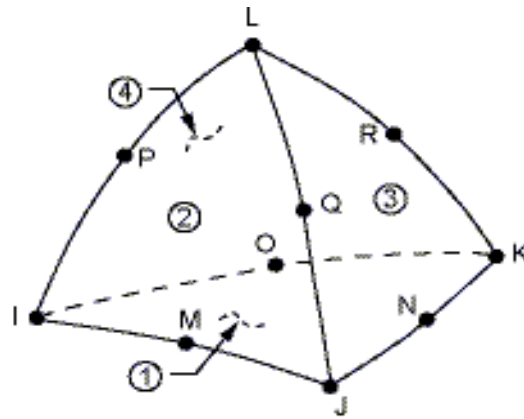


Fig. 8. Geometry of the Solid 187 element.

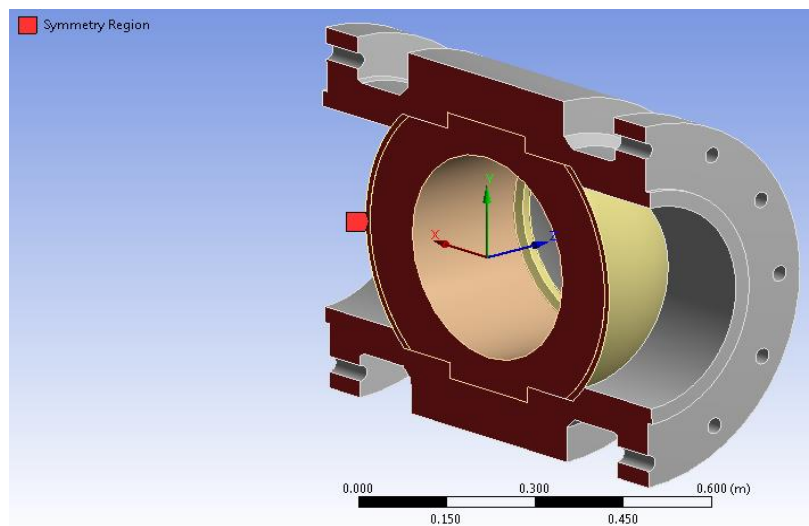


Fig. 9. Illustration of symmetry planes in the ball valve simulation.

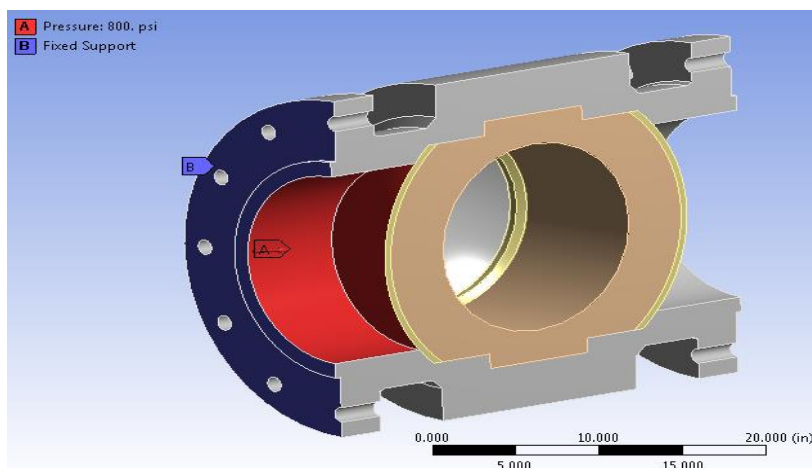


Fig. 10. Illustration of boundary conditions applied to the ball valve.

4 | Results and Discussion

In this section, the results extracted from the simulation of the Teflon-sleeved ball valve are presented. *Figs. 11-14* illustrate the von Mises equivalent stress contours for the body, the ball, and the sleeve on the ball, respectively. In *Figs. 15 and 16*, the trends of the sleeve's safety factor variations relative to the sleeve thickness under pressures of 250, 800, and 1000 psi are presented, respectively. It is expected that with an increase in

applied pressure, the resulting von Mises stress increases, consequently leading to a lower safety factor. As expected and observed in *Fig. 16*, the safety factor corresponding to a pressure of 1000 psi is lower than the safety factor for 800 psi. Furthermore, it is expected that by increasing the thickness of the sleeve on the ball, the resulting von Mises stress would decrease and the safety factor would increase. However, as observed in *Figs.15* and *16*, this does not hold true for certain design points. This is because, with an increase in sleeve thickness, the effective surface area under pressure increases; consequently, a higher von Mises stress and a lower safety factor are obtained. Therefore, for the sleeve thickness, both a direct effect and an indirect effect—due to the impact on the effective cross-sectional area under pressure, can be considered, where in some cases the direct effect dominates the indirect effect, and in others, the reverse occurs.

Analysis of the results indicates that the Von Mises stress distribution reaches its maximum value at the edges of the sleeve (the contact point with the seat). This phenomenon is consistent with stress concentration theories in objects with discontinuous geometries. A closer examination of the stress gradient across various thicknesses reveals that an optimal thickness exists, where a balance is established between the structural rigidity of the sleeve and its elastic deformability required for effective sealing.

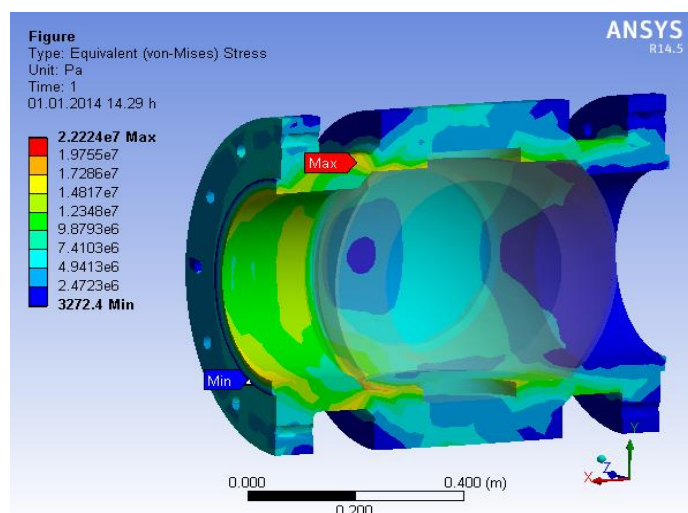


Fig. 11. Von Mises equivalent stress contour of the main ball valve body.

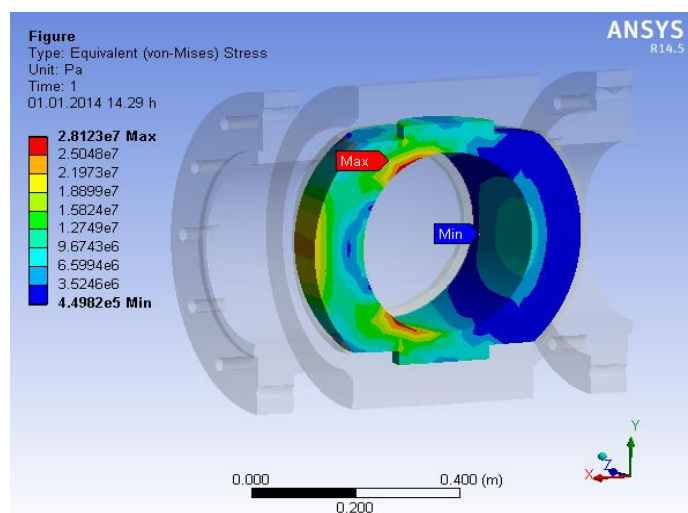


Fig. 12. Von Mises equivalent stress contour of the valve ball.

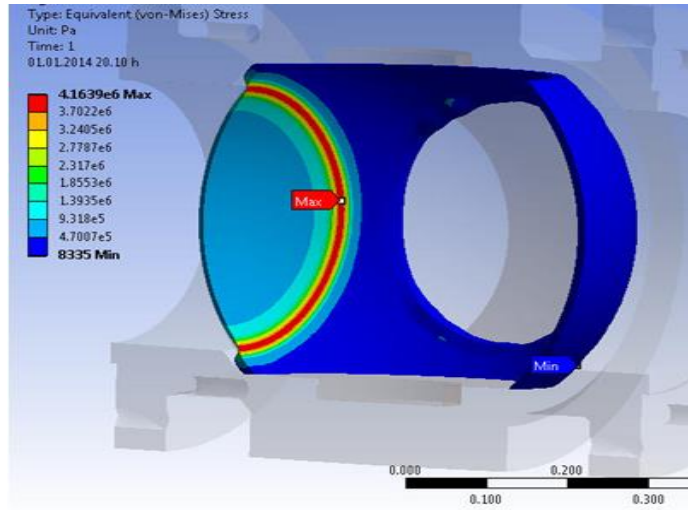


Fig. 13. Von Mises equivalent stress contour of the sleeve on the valve ball (view 1).

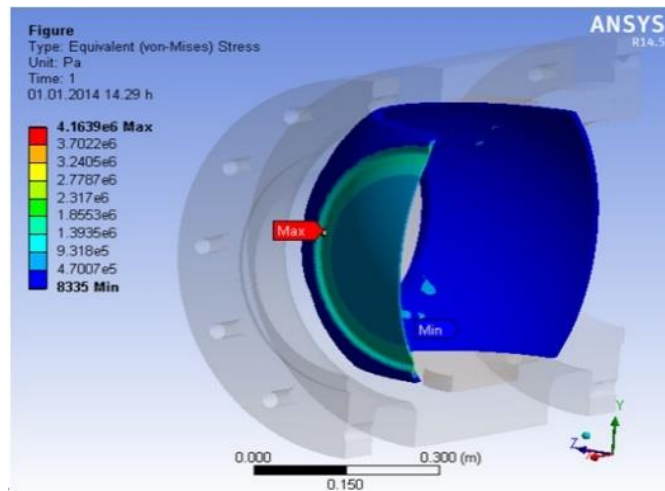


Fig. 14. Von Mises equivalent stress contour of the sleeve on the valve ball (view 2).

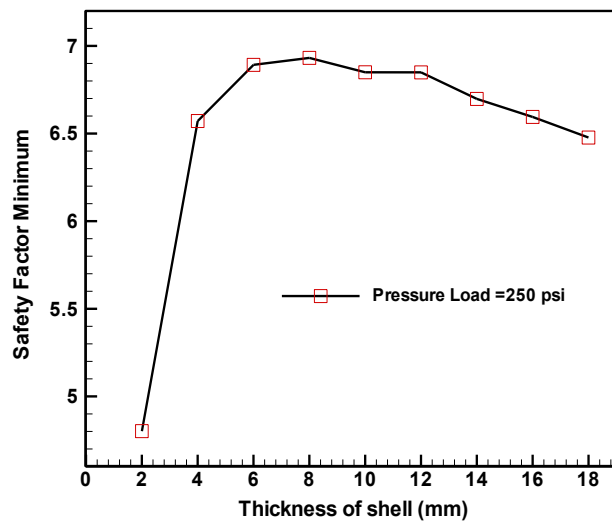


Fig. 15. Variation of the sleeve safety factor vs. thickness at 250 psi pressure.

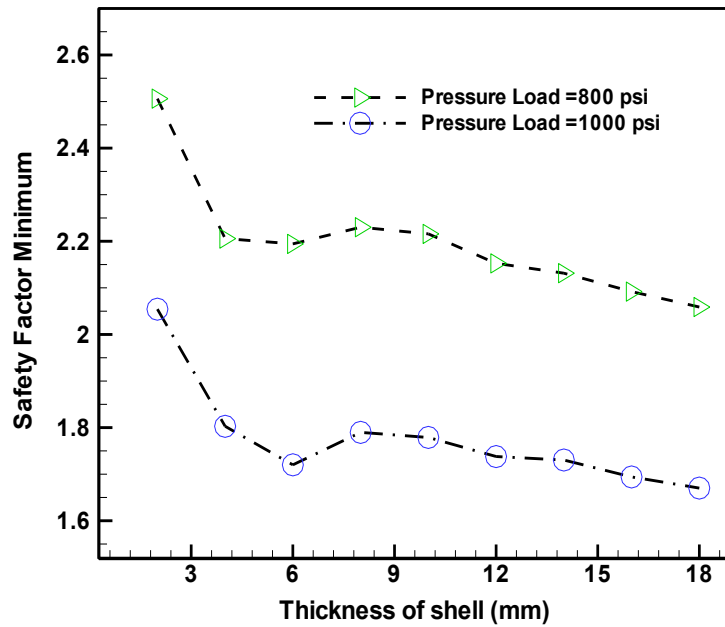
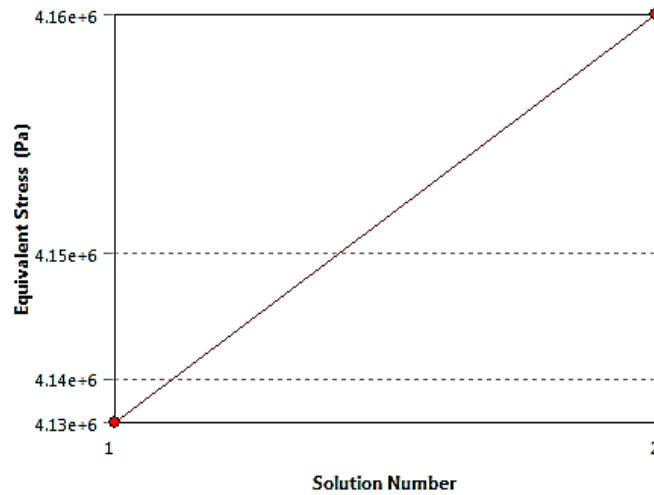


Fig. 16. Variation of the sleeve safety factor vs. thickness at 800 and 1000 psi pressure.



	Equivalent Stress (Pa)	Change (%)	Nodes	Elements
1	4131497.429		121326	72976
2	4163923.89	0.7817917793	268484	172798

Fig. 17. 3D model of the assembled ball valve.

5 | Conclusion

In this paper, the feasibility of the idea of placing a Teflon sleeve on the ball of an industrial ball valve has been investigated. The stress-strain diagram of the Teflon sleeve was extracted at room temperature and a strain rate of 10^{-4} per second, and it was utilized in the simulation of the Teflon sleeve in a non-linear manner. The von Mises equivalent stress contours for the body, the ball, and the Teflon sleeve have been presented. Furthermore, the diagrams of the sleeve’s safety factor variations relative to thickness changes under different

pressures were provided. Finally, to verify the accuracy of the presented results, the independence of the Teflon sleeve's von Mises equivalent stress from the number of elements (mesh independence) was demonstrated. In this study, although thermal properties affect the mechanical behavior of the Teflon sleeve material, these effects were neglected.

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No funding was received for conducting this study.

Data Availability

All data are included in the text.

Conflicts of Interest

The authors declare no competing interests.

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