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SUITABILITY OF HYPERELASTIC MATERIAL MODEL FOR ANALYSIS OF WATER DISTRIBUTION SYSTEM

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ABSTRACT

Pipelines have been increasingly used as an efficient and economic means for the transportation of large quantities of resources such as water, fuel and gases. While there are various modes of transporting resources, pipeline systems happen to be among the safest. In the present study, the integrity of different components of the distribution network is checked for the sustainability of its designated pressure. The rubber gasket used as a sealing element in the distribution system is made from ethylene-propylene diene monomer (EPDM) and is tested to determine its stress–strain behavior, which is further analyzed in finite element analysis. From the study, it is concluded that the Mooney-Rivlin nine-parameter model is best suited for EPDM, and full analysis of the joint shows that it can sustain the designated pressure without failure. In this way, a new class of pipe can be designed without an experimental setup, which is very costly and requires considerable space. This will revolutionize the distribution field and save the surrounding environment affected by leakage and failure.

Keywords: Hyperelastic Material, Water Distribution System, Sealing Element, Mooney-Rivlin Model, Finite Element Analysis.

INTRODUCTION

For the efficient and affordable transportation of large volumes of water to fields for irrigation purposes, pipelines have become increasingly popular. While there are various modes of transporting water, pipeline systems happen to be among the safest. It is a major problem to maintain such a large network system safely across the country (Ab Ghani et al., 2011). To guarantee its safety, the overall integrity of the systems must be ensured before they are deployed into service (Patel and Mehta, 2022). Therefore, for the water pipeline to operate safely, a workable system for inspection and monitoring must be developed. Hydrostatic testing is commonly used to test and confirm this integrity.

Currently, pipelines are extensively used for conveying any material existing in any of the three states of solids, liquids and gases. Conveyance of material through pipes has a number of advantages over other modes of transportation and hence is gaining popularity and acceptance (Sahu et al., 2022a, 2022b). With the help of pipes, it is safely and conveniently possible to convey material over long distances through urban dwellings and beyond geographical obstacles. There are numerous examples where pipelines have been employed to transport sediment, grains, liquids of different reactive characteristics and gases. In India, the pipeline Hajira-Bijapur-Jagdishpur has been a successful model of the Gas Authority of India, Ltd. (Verma et al., 2022,2023).

Furthermore, the water for irrigation, which was predominantly conveyed through open channels, is rapidly replaced by closed pressurized or nonpressurized conduits. This saves precious resources from losses due to seepage and evaporation (Vijaykumar et al., 2022).

The basic components of a water distribution system include pipelines, valves, storage tanks, and pumping stations (Yadav et al., 2015). Water reticulation pipes stand out among these sections because they are essential to both urban and rural areas and are frequently regarded as the most crucial maintenance resources for water delivery systems (Grigg, 2019). Water mains are regularly placed under a variety of operational and environmental conditions, which causes them to deteriorate. Water quality deterioration frequently has negative effects on water quality, water losses, and operation and maintenance expenses. While manufacturing the pipes, it should be checked for the maximum pressure it can sustain without failure as per the pressure class of pipes (Waikhom and Mehta, 2015). Against this backdrop, there is also often a need to improve the reliability of the system and to improve the service delivered to the users.

A key challenge that has attracted the attention of many researchers in the field of water distribution networks during recent decades is the development of various facilities to check for maximum pressure along with safety factors.

A crucial component of the water distribution system is the pipe junction. One of the contributing elements to the leakage issue was a weak joining system and a crack in the pipe construction (Shital et al., 2016). This situation may reduce the effectiveness of the piping and water distribution systems that handle NRW. NRW, which is typically expressed in terms of steel pipe, refers to the volume of water added to supply systems that generates no revenue for the water supply authority (Chellapan et al., 2017). Different connecting systems, including flanged joints, welded joints, flexible mechanical couplings, and push-fit spigot-sockets, can be used to link this pipe. As a substitute joining mechanism for steel pipelines, the push-fit spigot-socket steel pipe is offered since it may make pipe joining easier and reduce installation costs (Lungariya et al., 2016). This push-fit technique has not been commonly employed, especially for large-diameter pipes used for water distribution, in steel pipes. This is a result of the lack of design information for such a component, particularly the elastomeric seal. To block a passageway and stop a fluid or gas from escaping or losing pressure, the seal is often created as a circular ring with different cross-sectional configurations in a gland (Phelps et al., 2021). Elastomer is an isotropic, extremely deformable, highly elastic, and almost incompressible material. It is a polymer that exhibits elasticity and is frequently used as a substitute for rubber.

Rubber has a special gripping ability and an extremely high static coefficient of friction against most dry surfaces, typically around unity.

Water utilities' main responsibility is to use a distribution network to deliver water under appropriate pressure and in the required quantity to each individual customer. Most Indian cities only have intermittent water pressure, sporadic water supply availability, and water of uncertain quality (Mehta et al., 2016a, 2016b, 2017a, 2017b).

Cast iron pipe (CIP) was converted into ductile iron pipe (DIP) by adding inoculants, such as magnesium, to the molten iron to change the distribution of graphite from a flake form to a sphere. Strength, impact resistance, and a few other qualities all improved as a result of this.

The study related to pipelines is generally industry oriented, and in the present study, an interlink is established between industry and institutional research. For this purpose, rubber gaskets that act as sealing elements are analyzed by carrying out various tests to determine their stress–strain behavior under different conditions. The present study will also fill in the gaps in information in the studies of the transportation of liquid through pipes as well as the failure of pipes for various reasons.

LITERATURE REVIEW

This section consists of a detailed review of findings from an extensive literature search. Analytical studies are performed with the help of different software programs by creating models of joints due to difficulty in the experimental setup. Conventional experimental methods for solving stress and strain become very complex and almost impossible when the component geometry is very complex. In such situations, finite element modeling becomes a superior and convenient method to carry out the analysis. In the finite element process, discretization of the whole geometry is performed to divide the geometry into small fundamental volumes, which are known as finite elements. The governing equations and material model properties for these elements are entered in the finite element process (Zeinalie et al., 2021). These discretized elements are then fabricated by taking proper care of constraints and loading, which results in a set of equations. These resulting equations, when solved with FEA, give the result that describes the behavior of the original complex body that is being analyzed.

Mathan et al. (2008) conducted experiments on gasketed flange joints and analyzed bending loads in flange joints through FEA considering the nonlinear properties of the gasket. The contact stress distributions observed had significant variation along the gasket width and in bolts under bending loads, and the results were compared with the experimental studies. Do et al. (2011, 2014) proposed an analytical approach to determine the effect of bolt spacing and its impact on flange design based on the theory of circular beams. The model was tested for different bolted joints by varying the number of bolts, flange and gasket stiffness. When the analytical and FEA findings were compared, it was found that the stiffness of the gasket and the flange thickness had a significant impact on stress distribution.

Yang et al. (2011) conducted laboratory experiments on the pull-out of rubber gasketed joints for ductile iron pipes of 150, 200, and 300 mm in diameter. Pipeline damage is primarily caused by axial displacements that outweigh lateral deformation. Han Yuan thus performed the axial pulling out test for ductile iron pipes with flexible joints. The study's findings indicate that the flexible joint of ductile iron pipes exhibits axial force–displacement relationships that exhibit nonlinear behavior and pronounced variability and that the stiffness value of these relationships is affected by a variety of variables, including internal water pressure, the caliber of the rubber gasket, friction between the pipe and the gasket, and the loading velocity. The increased axial displacement of these joints is permitted because the axial tension test shows that rubber gasketed joints are efficient in providing a flexible and leakproof connection for jointed subterranean pipelines.

To characterize 6-in. (150-mm) diameter DI push-on joints, Wham et al. (2016) report on a series of specially constructed four-point bending experiments under 55 psi (380 kPa) of internal water pressures in comparison with 3D finite-element (FE) models. The findings were used to estimate the magnitudes of rotation and moment that start joint leaking as well as to develop a link between rotation and metal binding as a function of axial pull-out. The elastomeric gasket material was subjected to uniaxial tension and one-dimensional compression tests, which were utilized to create a hyperelastic strain energy model of the gasket for use in numerical modeling to characterize behavior under high loading (Prasad and Ahmad, 2022). Numerical simulations show that joint leakage is independent of the load path and that leakage is predicted by a single pressure boundary for a wide range of deformation combinations.

According to Rajeev et al. (2014), internal water pressure, which includes static water pressure and pressure transients caused by surges, external loads, the weight of the pipes and their contents, the heaving or movement of the surrounding soils, and potential inertial seismic forces, is a problem for subterranean pipes. Earth loads and traffic loads are the two main types of external loads. External loads create nonuniform stress conditions (bending) along the pipe's circumference as opposed to the uniform stress condition created by internal pressures in the absence of any other external loads (Makubura et al. 2022). If the combined stresses caused by all of these loads are sufficiently greater than the pipe capacity, a pipe with corrosion or another comparable problem may fail.

A nominal 8-in. (200-mm) ductile iron pipeline with earthquake resilience underwent a large-scale fault rupture test by Oda et al. (2017). The test resulted in evidence that the pipeline behaved like a chain structure to allow for fault movement. Analytical and experimental findings were compared after numerical modeling of the pipeline behavior in the fault rupture test. The design of a DI pipeline system that could handle a significant ground displacement was subsequently performed using the finite element model (FEM).

Pipe couplings with gasketed bolted flanges are known to leak frequently when in use. As a result, the right joint assembly with a proper gasket, proper gasket seating stress, and proper preloading in the bolts of a joint are all crucial for a gasketed flange joint's functioning (Azamathulla et al., 2008). The joint strength and sealing ability are the two key issues with a gasketed flange joint. It has been established that, depending on the application or use, a flanged pipe joint is subjected to external loading in various combinations (Emadi et al., 2022).

More recently, US manufacturers created DI pipeline systems with unique constrained joints that may rotate and slip to accommodate ground deformation brought on by earthquakes (Lambey et al., 2019). The inventory of jointed DI pipelines that can be employed to improve performance in response to earthquakes and other hazard-related causes of differential soil movement is significantly increased by these items.

Overall, it can be seen and understood that while considerable amounts of research have been done on pipe joints, ductile iron pipe joints have received significantly less attention. Additionally, there is a significant variance in the types of gaskets utilized as sealing elements in experiments. Because of this, generalizing the findings of such research is challenging. From the above discussion, the gasketted joints in ductile iron pipes for higher pressure applications are in an underdeveloped stage, and future works in the laboratory as well as in the field should be planned and directed toward gasketted joint studies.

MATERIALS AND METHODOLOGY

Materials and methodologies for analysis are described in this section. Various tests are performed on the parent materials to determine their properties.

Materials

In the present study, the main materials under consideration are ductile iron and EPDM. Various tests are performed on both materials to determine their properties. The pipes under consideration in the present study are made of ductile iron. Various tests are performed on the ductile iron sample to determine its mechanical properties.

The rubber gasket, which acts as a sealing element, is made of EPDM. Ethylene-propylene diene monomer is known as EPDM. Withstanding heat, oxidation, and the aging effects of ultraviolet light, EPDM is an extremely stable polymer. In contrast to many other elastomers, it can function between -60°F and 300°F depending on how it is formulated. Additionally, EPDM offers strong mechanical qualities. The range of 7 to 21 MPa is higher than that of other elastomers in terms of tensile strength.

Different tests are carried out on rubber gasket samples to determine their material characteristics.

- Uniaxial Tension Test
- Uniaxial Compression Test
- Planar Shear Test
- Volumetric Compression Test

These tests are carried out as per ASTM D412, an international standard test designed for testing the tensile strength of rubber and thermoplastic elastomers. The stress–strain behavior of EPDM obtained from the above tests is shown in Figs. 1-4.

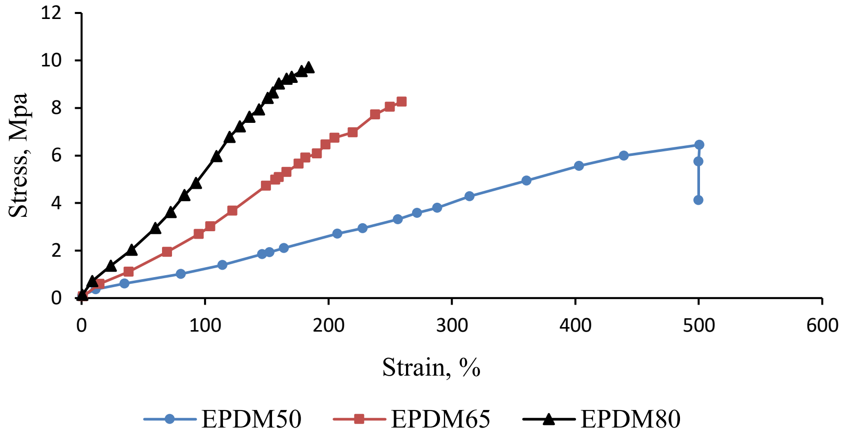

Figure 1: Uniaxial Tension Test Results of EPDM 50, 65 and 80

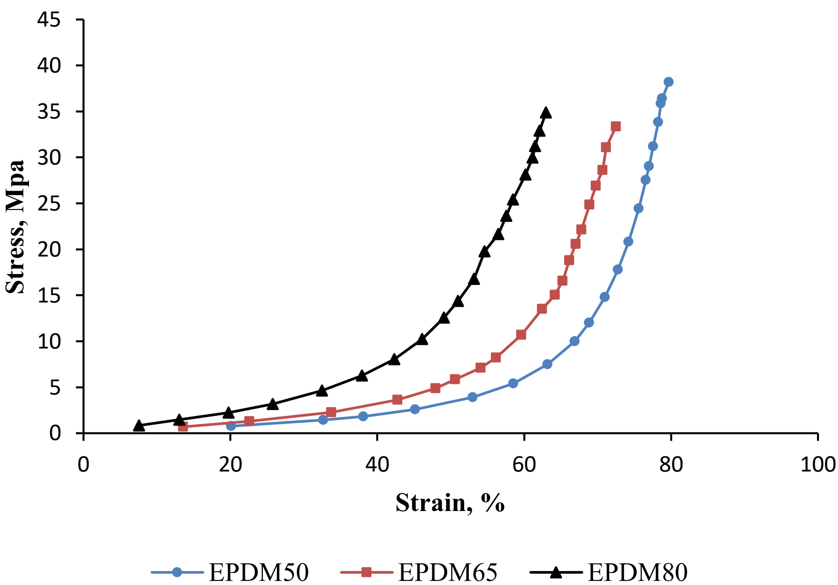

Figure 2: Uniaxial Compression Test Results of EPDM 50, 65 and 80

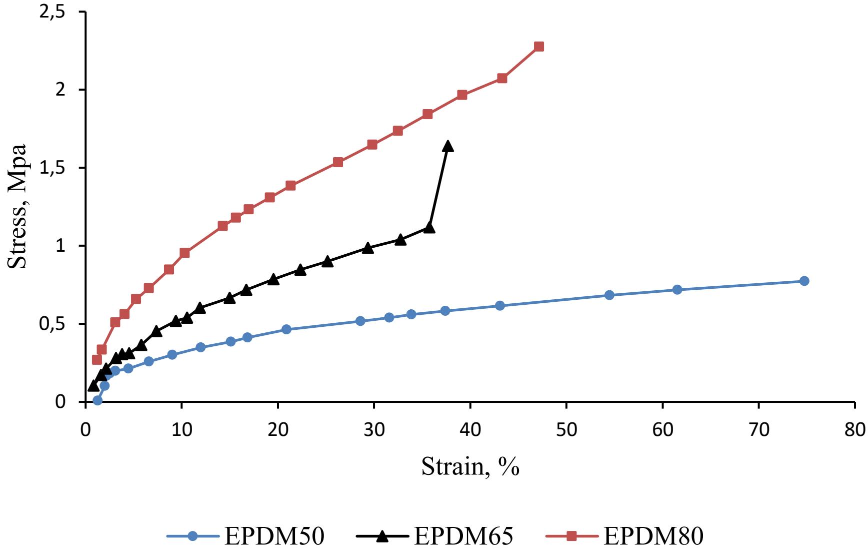

Figure 3: Planar Shear Test Results of EPDM 50, 65 and 80

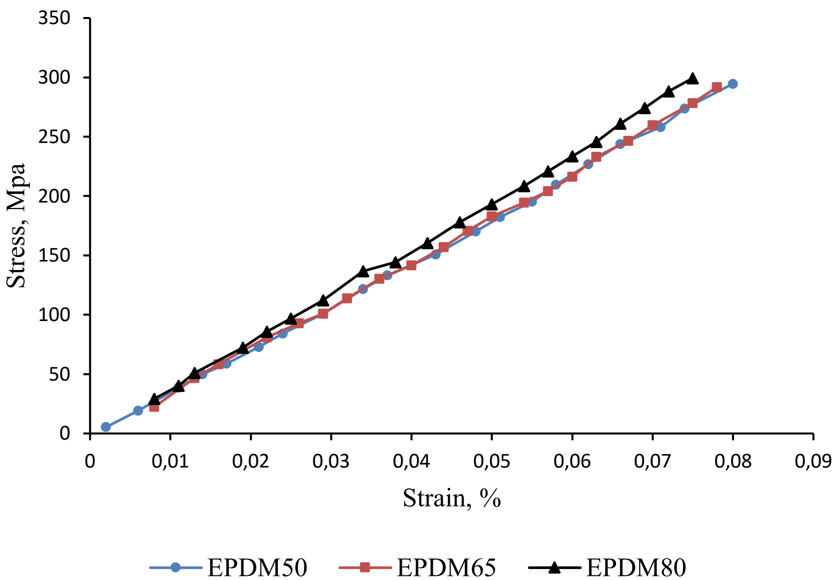

Figure 4: Volumetric Compression Test Results of EPDM 50, 65 and 80

Methodology

Gasketted joints are analyzed with the help of finite element analysis in ANSYS software with the actual properties of both materials. One of the most significant discoveries in numerical analysis is the finite element approach. Engineering challenges can be accounted for numerically in a variety of ways, but finite element analysis (FEA) is an adaptable and comprehensive approach for resolving complicated design issues. For the past three decades, numerical techniques, particularly those that use finite element methods, have been used to simulate rubber and rubber-like materials. FEA eliminates the need to create and use complicated equations to analyze complex structures.

FEA involves a variety of equations of systems and resolves them roughly. It goes through several stages, starting with the discretization of the entire geometry into tiny parts. Following discretization, the system equation is obtained by combining these attributes and evaluating the finite element characteristics (Chaplot et al., 2021). In this order, the problem-specific boundary conditions and actual loads are applied, and system equations are solved to produce effective results. The nodes of the elements contain the solution's outcome. They can be visualized graphically using finite element analysis so that they can be analyzed so that design judgments and suggestions can be made.

Rubber-like materials, which have a high bulk modulus and a relatively moderate elastic modulus, are used in many different structural applications. These materials are referred to as "hysterelastic material" because they frequently encounter enormous elastic strains and deformation with little volume change (almost compressible material). If there is an elastic strain density function (W), which is a scalar function of the strain deformation tensors and whose derivatives with respect to the strain components define the corresponding stress components, then the material is said to be hyperelastic. As a result, the hyperelastic constitutive model has both substantial deformation and material nonlinearity.

One of the crucial steps in the FEA process is material modeling. The application, corresponding factors, and data available to establish the material parameters all influence the model choice. Commonly, solid elements with a specific isotropic hyperelastic material model are used to simulate rubber blocks. Although numerous theoretical models were created to describe the mechanical behavior of rubber, the Mooney Rivlin model is one of the most significant ones. Most commercial FEA programs include this model, which is widely used for the stress analysis of rubber components. The large-scale material displacement and deformations are predicted by the material models. The Mooney-Rivlin, Arruda-Boyce, and Ogden material models perform well in the analysis of incompressible rubber materials. Below is a list of the significance of the material models at various strain rates.

- Mooney-Rivlin model strain of up to 200%.
- The Arruda-Boyce model strains up to 300%.
- The Ogden model strain of up to 700%.

Numerous models have been proposed to anticipate and examine the mechanical characteristics of these hyperelastic materials. Neo-Hookean, Mooney-Rivlin, Ogden, Arruda-Boyce, Gent, Yeoh, Blatz-Ko, etc., are examples of common hyperelastic models. These models are currently utilized widely in a variety of industries, including computer-generated imagery in motion pictures, rubber products (such as rubber seals), biological materials (such as muscles), and rubber products.

Engineers typically have little solid data to draw conclusions from when a finite element analysis model includes hyperelastic materials. An engineer may occasionally be fortunate enough to have data from tension, compression, stress–strain, or straightforward shear tests. A crucial step in analyzing the hyperelastic models is processing and using these data. It is crucial to curve-fit these data to determine the material constants.

The chosen hyperelastic model's mechanical response is governed by the material constants in the strain-energy function. We must analyze material constants from the tested samples to obtain accurate analytical results. These parameters are often found by fitting curves to experimental strain–stress data. These test results typically come from a variety of deformation modes under various strains. Test data in at least as many deformation states as would be encountered in the finite element analysis could be used to fit the material constants.

All the tests carried out on the parent materials and various things which should be kept in mind from the stage of manufacturing of pipes to lay down the pipelines should be as per standards. After the engineering properties of different materials are inserted, the next step in preprocessing is the creation of geometry. In the present study, there are three components, i.e., socket, shot and gasket. The drawings of the socket and gasket are shown in Figs. 5 and 6 along with the dimensions in Tables 1 and 2. The geometry of different components is created as per the drawings either in ANSYS or CAD and can be exported to ANSYS.

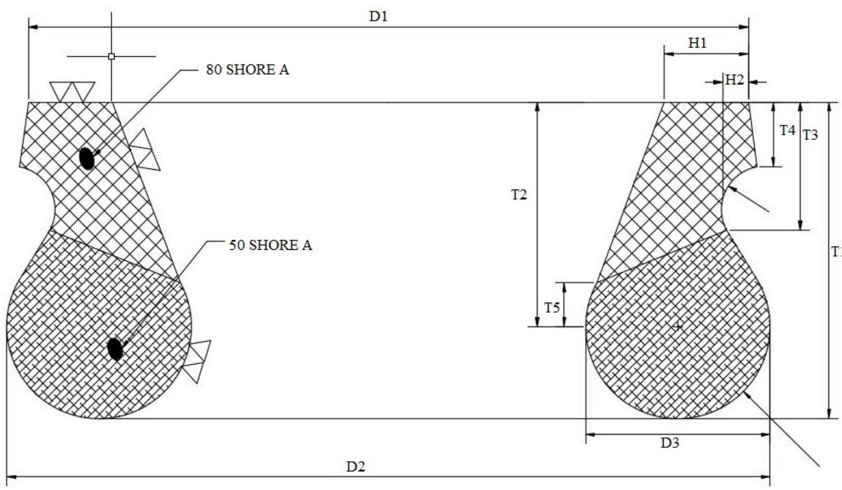

Figure 5: Drawing of a TJ-type Gasket

Table 1: Dimensions of TJ-type Gaskets

DN	D1	D2	D3	H1	H2	T1	T2	T3	T4	T5
700	809	803	33.5	20	10	55	39	24	16	8

The next step in the sequence is modeling of the project. In modeling, the materials that are created in the first step are assigned to different parts of the geometry. The socket and spot are assigned as ductile iron, and the gasket is assigned as an elastomer sample whose properties are already defined in the first step.

The contacts between different parts are set up by defining the contact body and target body. In this study, there will be two types of contact, i.e., frictional and bonded. A bonded connection is set up between two different parts of the gasket, and a frictional connection is provided for gasket contact with the socket and spigot. The friction coefficient is kept at 0.15 in the frictional connection.

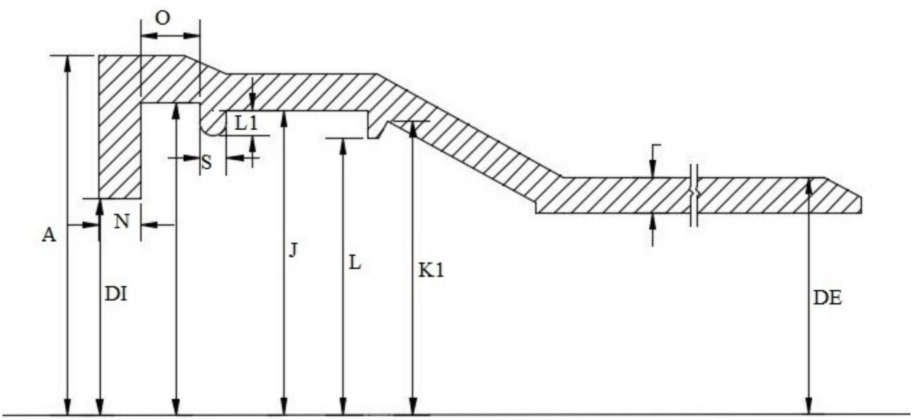

Figure 6: Drawing of the Socket Component of the Joint

Table 2: Dimensions of the Socket Component of the Joint

DN	A	DE	DI	J	L	K1	O	S	L1
700	813	738	740.5	779.3	748.5	766.7	18	12	10

Meshing of the geometry is performed by selecting the all triangle method, in which the whole geometry is divided into small triangles with well-defined element sizes, individual triangles will be solved, and the final result will be integrated, which is the basic principle of ANSYS.

The displacement of the spigot is defined in tabular form with movement only in the Y-direction, and the X-component is zero. During insertion of the spigot into the socket, it should reach up to the defined displacement by compressing the gasket. The gasket should be fitted in its groove so that a leak-proof joint can be created.

Two edges of the socket are kept fixed so that when the spigot is inserted into the socket, there should be no movement of the socket Spigot should insert smoothly up to its marked displacement while compressing the gasket. After insertion, pressure is applied on the gasket gradually up to 70 bars with a suitable interval. In this case, we applied pressure starting from 1 bar to 70 bars with a 1 second interval. If the joint can sustain 70 bar pressure safely, then it will be verified experimentally with the same dimensions.

RESULTS AND CONCLUSION

Based on the stress–strain behavior of rubber gaskets, the material constants of various hyperelastic material models, such as the Mooney-Rivlin 2-parameter, 3-parameter, 5-parameter, 9-parameter, Aruda Boyce, Neo-Hookean, and Yeoh 1st-order, 2nd-order and 3rd-order models, are determined by the curve fitting method. The four tests performed for the determination of stress–strain behavior are very costly, and limited facilities are available in India. Therefore, these material constants can be directly used if the material properties resemble those of the rubber gasket. In the continuation, residual errors are also calculated to select the most appropriate material model. In the present study, the Mooney-Rivlin 5-parameter model is used, although as per the residual error, the Mooney-Rivlin 9-parameter model was most appropriate, but the complexity of a particular problem should also be considered while selecting the material model. The material constants for different hyperelastic material models are shown in Tables 3-6 along with the residual errors.

In ANSYS, when the gasketed joint is analyzed with the actual properties of ductile iron and rubber gaskets, the joint is found to be safe under designated pressures. By following the same procedure, we can check the sustainability of any joint. For physical testing, there is a requirement for a large setup, which will be very costly, and the chances of bursting of the pipe are also high if all the components do not meet the required standards. In this way, a new class of pipe can also be designed by changing the different design parameters and making the required changes as per the error that occurred during analysis.

Table 3: Material Constants for the Mooney-Rivlin Two-Parameter Model

Name of Model	Name of Material	Material Constants	Value (Four Tests)	Only uniaxial
Mooney Rivlin Two Parameter Model	EPDM50	C10	5586.2	0.0058837
		C01	16.237	0.066664
		D1	8.5411×10^{-7}	0
	Residual Error		25.148	0.36343
	EPDM65	C10	17349	0.015449
		C01	20.812	0.0088525
		D1	3.699×10^{-8}	0
	Residual Error		13.679	0.090408
	EPDM80	C10	29140	0.026207
		C01	45.303	0.053666
		D1	3.2152×10^{-8}	0
Residual Error			11.742	0.078654

Table 4: Material Constants for the Mooney-Rivlin Three-Parameter Model

Name of Model	Name of Material	Material Constants	Value (Four Tests)	Only Uniaxial
Mooney Rivlin Three Parameter Model	EPDM50	C10	5653.5	0.0065161
		C01	3.6656	0.062866
		C11	0.0010994	-6.906×10^{-7}
		D1	8.5411×10^{-7}	0
	Residual Error		23.658	0.32041
	EPDM65	C10	17652	0.014194
		C01	1.4628	0.011951
		C11	0.0018798	2.62×10^{-6}
		D1	3.699×10^{-8}	0
	Residual Error		12.55	0.071031
	EPDM80	C10	29349	0.024152
		C01	27.887	0.059057
		C11	0.0020802	5.699×10^{-6}
		D1	3.2152×10^{-8}	0
	Residual Error		11.555	0.061184

Table 5: Material Constants for the Mooney-Rivlin Five-Parameter Model

Name of Model	Name of Material	Material Constants	Value (Four Tests)	Only Uniaxial
Mooney Rivlin Five Parameter Model	EPDM50	C10	5551.9	0.47974
		C01	25.33	-0.56301
		C20	0.00058	-1.78×10^{-8}
		C11	-0.00368	7.366×10^{-6}
		C02	9.61×10^{-7}	-0.11923
		D1	8.54×10^{-7}	0
	Residual Error		22.463	0.15508
	EPDM65	C10	18808	1.3687
		C01	19.92	-1.8581
		C20	-0.035	-8.42×10^{-8}
		C11	-0.0027	2.57×10^{-5}
		C02	1.09×10^{-6}	-0.34052
		D1	3.69×10^{-8}	0
	Residual Error		11.953	0.0021467
	EPDM80	C10	30759	0.82349
		C01	58.14	-0.98662
		C20	-0.081	-2.58×10^{-7}
		C11	-0.0078	5.448×10^{-5}
		C02	2.99×10^{-6}	-0.20255
		D1	3.21×10^{-8}	0
	Residual Error		11.208	0.0088026

Table 6: Material Constants for the Mooney-Rivlin Nine Parameter Model

Name of Model	Name of Material	Material Constants	Value (Four Tests)	Only Uniaxial
Mooney Rivlin Nine Parameter Model	EPDM50	C10	5191.7	-4.2052
		C01	36.518	5.0379
		C20	0.01472	-0.007781
		C11	-0.010012	-1.8677
		C02	-2.8776×10^{-6}	3.8698
		C03	5.1016×10^{-14}	0.46983
		C12	-4.3148×10^{-10}	0.0019452
		C21	2.245×10^{-6}	7.45×10^{-11}
		C30	-4.7254×10^{-8}	-1.5×10^{-13}
		D1	8.5411×10^{-7}	0
	Residual Error		22.032	0.12288
	EPDM65	C10	19759	1.0713
		C01	20.293	-1.445
		C20	-0.087549	0.001122
		C11	-0.005649	0.0083978
		C02	0.00068468	-0.28005
		C03	4.2135×10^{-14}	-0.0025228
		C12	-2.7764×10^{-10}	-0.00028038
		C21	-0.00017029	-9.047×10^{-10}
		C30	1.8048×10^{-6}	2.246×10^{-12}
		D1	3.699×10^{-8}	0
	Residual Error		11.74	0.0014095
	EPDM80	C10	34295	-7.8894
		C01	99.304	9.4265
		C20	-0.32294	0.022602
		C11	-0.04825	-3.4898
		C02	0.003224	7.1671
		C03	6.4792×10^{-13}	0.86394
		C12	-4.1856×10^{-9}	-0.0056947
		C21	-0.00079569	-6.772×10^{-9}
		C30	1.2291×10^{-5}	2.04×10^{-11}
		D1	3.699×10^{-8}	0
	Residual Error		10.588	0.0012719

In the present study, the analysis of a C-64 class DI pipe with a diameter of 700 mm (DN700) is carried out, which is already in operation. In this case, C represents the class of pipe, and 64 represents the maximum pressure it can carry safely without failure. All the boundary conditions and various loading conditions should be kept the same as per the field conditions. If any condition during analysis does not meet the actual conditions, the solution will not converge. In that case, either the socket will not fully insert into the spigot or the gasket will burst or leave its actual position. All these scenarios are shown in the results section in Figs. 7 and 8 for reference purposes. In Fig. 7, the converged solution of the gasket is shown, in which when pressure is applied on the joint, the sealing element in the form of a rubber gasket will deform from its actual position. When the gasket is fully deformed between the socket and spigot, it will not leave any space and prevent leakage from the joint, which can further lead to contamination of the nearby environment, and in the case of gas and oil, it can also lead to severe accidents. In Fig. 8, an unconverged solution of the joint is shown. When the pressure is increased from its designated class, the rubber gasket will leave its position between the socket and spigot, and the space created for this reason will lead to leakage from the joint. All analyses are carried out as per the standard BS EN 545:2010 (Ductile iron pipes, fittings, accessories and their joints for pipelines — Requirements and test methods). The only difference is that the present analysis is carried out in FEA, which can eliminate the large setup and will also be cost friendly. All the conditions that are present in the field conditions are strictly followed, and the geometry of different components of joints is created as per actual dimensions provided in the tabular form in the methodology. The integrity of the distribution system should be a top priority because it provides a better facility for transporting different resources, but if there is any leakage from the distribution network, it can cause a significant effect on the surrounding environment.

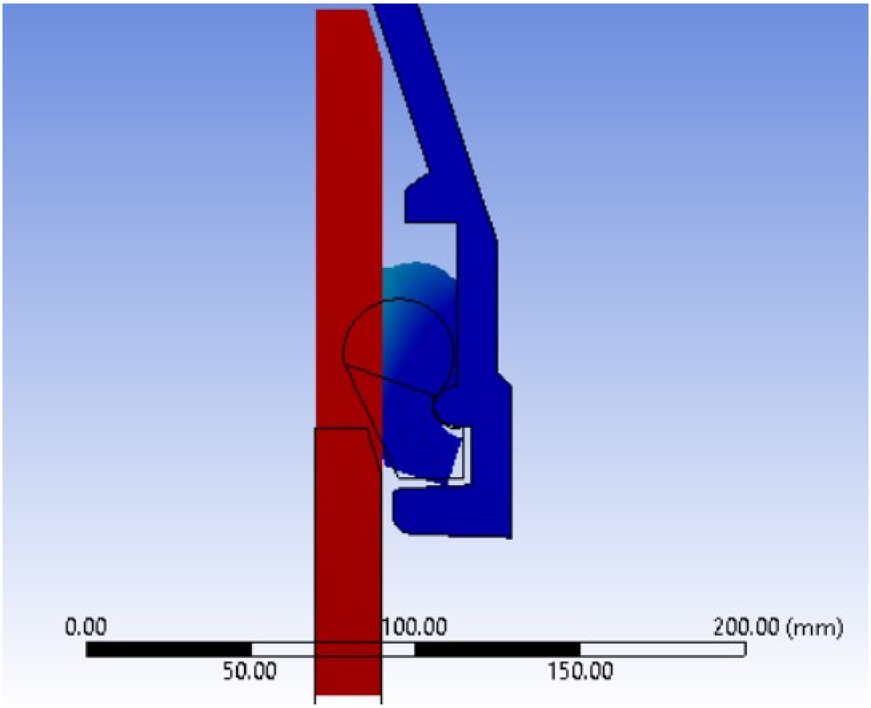

Figure 7: Converged Solution of a Gasket Joint with a Deformed Gasket

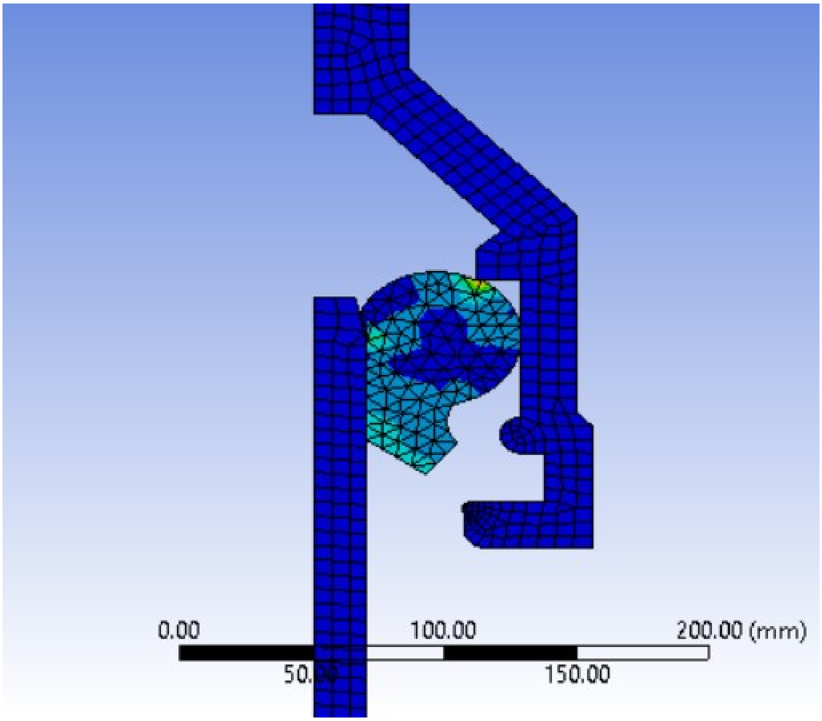

Figure 8: Unconverged Solution of Joint with Gasket not Fully Deformed

CONCLUSION

Based on the analysis carried out on the socket and spigot gasketted joint for ductile iron pipes, the following conclusions have been drawn:

a) For safe and leakproof joints, engineering data of both materials (rubber gaskets and ductile iron) should be inserted properly in ANSYS.
b) The Mooney-Rivlin 5-parameter model is selected for the present study based on the residual error and complexity of the problem.
c) Material constants of different hyperelastic models can be standardized for the particular material and can be used in the future if the parent material resembles the rubber gasket
d) By following the same procedure, a new class of pipe can be standardized by trying the different variables and resolving the errors encountered during the analysis, which will be a revolution in the field of irrigation by minimizing the losses that occur due to faulty joints.
e) The efficiency of joints can also be checked by this procedure, which will limit the losses that occur due to leakage in the surrounding environment and replace open channel flow.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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