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NONLINEAR FINITE ELEMENT ANALYSIS OF GASKETED FLANGE JOINT UNDER COMBINED LOADING CONDITIONS

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ABSTRACT:

Gasketed-flanged pipe joints have been widely used in industries for connecting pressure vessels and pipes. Joint strength and sealing strength are most important factors in the bolted flange joint. Most of the research work focused on the structural strength of the flange joint under internal pressure only. The research work does not consider the nonlinear behavior of gasket used in the flange coupling. The leakage and distortion of gaskets in bolted flange joints at high temperature is a well recognized problem and makes the problem more complex under combined application of internal pressure and temperature. To investigate the gasket sealing performance under the combined thermal and pressure load in the flange coupling, three different gasket materials with nonlinear behaviour will be considered for the application. A nonlinear finite element analysis of gasketed flange joint is carried out using ANSYS commercial software. The material nonlinearity for the Gasket and flange joint are considered to evaluate the deflection and stresses in the gasket. The suitable gasket material will be selected for the application. Finite element model is also verified with the available classical theories and experimental setup.

KEYWORDS: Gasketed- flanged coupling; Nonlinear; Contact Stress; Sealing strength; structural strength; FEM etc.

I. INTRODUCTION:

Most commonly bolted flange joints find application in hydraulic systems for joining individual elements. Their basic task is assurance of the tightness of connection. Another area of application is joining elements of machinery and devices. In that case the essential task of the connection is transfer of own loads and technological loads between elements.

Fig. 1 : Example of Bolted Flange Joint

Bolted flange joint is a mechanism to create and maintain a specific clamping force to join two pipes or pipe to equipment in all sorts of industries. Gasketed bolted joints are the weakest elements in most of the structures, where a product can leak or fail. Therefore proper preload is critical for the safety and reliability of a joint. Preload in the bolts is created during assembly process and clamping force is developed between the joint members. Consequently the right amount of clamping force developed initially dictates the overall behaviour of the joint. Predicting and achieving a given preload and clamping force is difficult as assembly process is affected by many variables. Torque control, turn control, stretch control and direct tension control methods are used for preloading the bolts in the bolted flanged pipe joints.

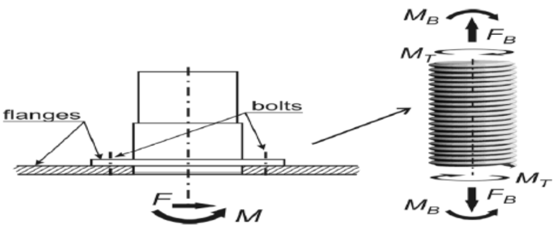


Fig. 2: Example of Bolted Flange Joint loaded with pretension

Torque control method using torque wrench is a widely used assembly procedure in the industry. In this procedure nut or bolt is turned against the surface of the flange to stretch the bolt. Each bolt is tightened individually in a defined tightening sequence. Due to the friction between threads of nut and bolt and joining surfaces, a fraction of the energy is stored in the bolt. Torsional stress becomes significant at high loads and bolt may yield prior to the actual yield threshold as the combination of axial and torsional stress exceeds the allowable value. Moreover as each bolt is tightened individually, elastic interactions come into play resulting in bolt scatter. In addition, any excessive preload can crush a gasket and it will not be able to recover. Upper limit for gasket contact stress is usually provided by the gasket manufacturer depending upon application, size and type of the gasket.

This paper presents results of the most common assembly procedures using nonlinear finite element analysis of gasketed bolted flange joints using different bolt up values. In addition behaviour of flange joint size under the application of two different target torque values is also discussed for any variation in joint's performance.

A. PROBLEM DEFINITION:

Gaskets are the most important parts in the coupling as far as leakage is concerned. The sealing performance is the prime parameter to be checked in the Pipe joints and pressure vessels. The failure in the gasket performance occurs due to different loading scenarios. The thermal effects introduce thermal stresses under internal pressure and bolt pretension in gasket.

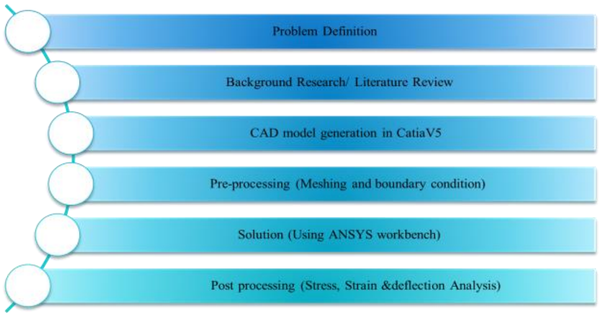
To overcome the problems in the gasket, the design of gasket should withstand the changing effect of temperature and pressure. The best suitable material for the application will solve the leakage problems and strength issues in flange joint and ultimately enhanced the service life of the components.

B. OBJECTIVE:

In order to solve above mentioned problem, main aim of the project is summarize below:

- To evaluate the sealing performance or leakage/strength of gasket in nonlinear analysis of flange joint structure in combine effect of internal pressure and temperature in torque control method.
- To check performance of three gasket materials against the thermo-structural loading.
- To select best suitable gasket material for the application.
- To prepare solid model of best suitable gasket material & prepare FEA model of the same.
- To perform non linear analysis in FEA tool to correlate it with experimental testing results.

C. METHODOLOGY:



D. SPECIFIED MATERIAL PROPERTIES:

Allowable stresses and material properties for flange, pipe, bolt and gasket (as a solid ring) are given in Table-1. A material property for flange is as per ASTM A105, for bolts is as per ASTM A193-B7 and for gasket is as per ASTM A182. Bilinear kinematic hardening for elasto-plastic material properties will be used during analysis.

TABLE I. MATERIAL PROPERTIES

Sr No	Material	Parts	Density, Kg/m³	Young's Modulus, N/mm²	Poisson's ratio	Allowable stress, MPa	Thermal Expansion Coefficien, mm/⁰C
1	Grey cast iron (SA105)	Flange	7.86e-9	173058	0.3	250	12.5e-6
2	Steel (SA193 B7)	Bolt	7e-9	168922	0.3	724	14.1e-6
3	Rubber	Gasket 1	2.68e-9	1640	0.49	40	3.0e-6
4	Neoprene	Gasket 2	2.14e-9	1400	0.47	35	2.0e-6
5	EPDM	Gasket 3	1.87e-9	1580	0.42	32	1.12e-6

II. MODELING OF GASKETED FLANGE JOINTL:

The Flange and gaskets are an extruded entity. The extruded cut profiles were applied on the top. The CAD model is created in the CATIA software. The accuracy of any simulation depends on how accurately the modelling work has been carried out. The Modelling of the Flanges, Bolts, Nuts and Gaskets are done by CATIA modelling software using the below mentioned dimensions.

A. "2DMODELING" OF FLANGE COUPLING:

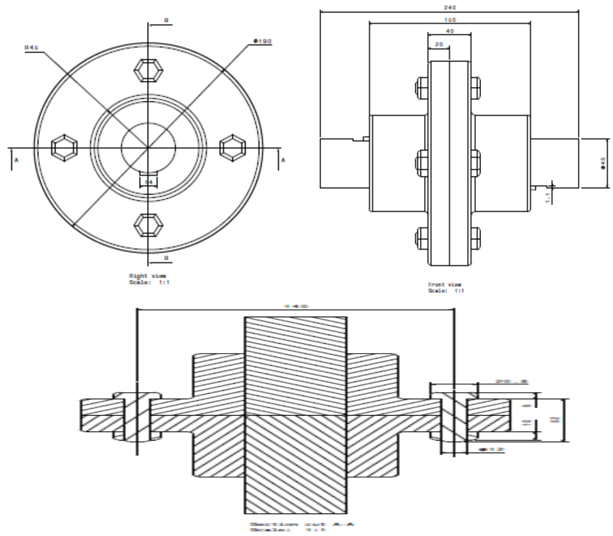


Fig.3: 2D' Views of Assembly Drawing

Outer Dia:190mm Gasket Thikness:8mm
Inner Dia:45mm P.C.D.: 140mm

B. "3DMODELING" OF FLANGE COUPLING:

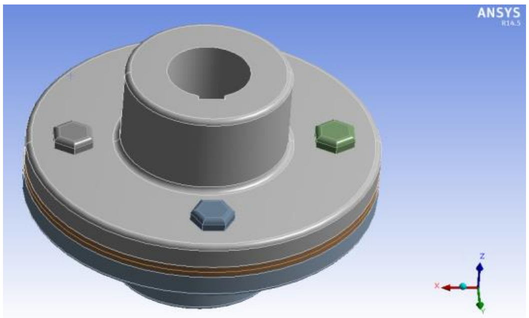


Fig.4: CAD model of Flange coupling

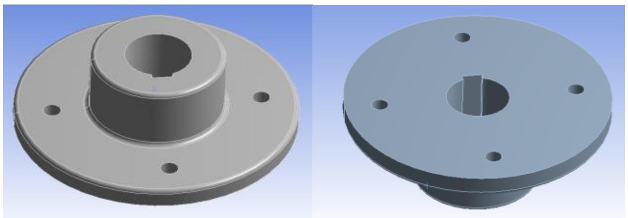


Fig. 5. CAD model of Upper & Lower Flange coupling

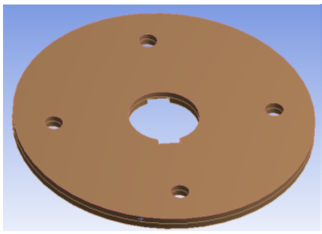


Fig. 6: CAD model of Gasket

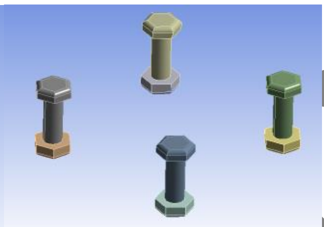


Fig. 7. Nut and Bolt assembly

III. FINITE ELEMENT ANALYSIS:

ANSYS software is used to mesh the solid model. Cad model which is in IGES format is imported to ANSYS.

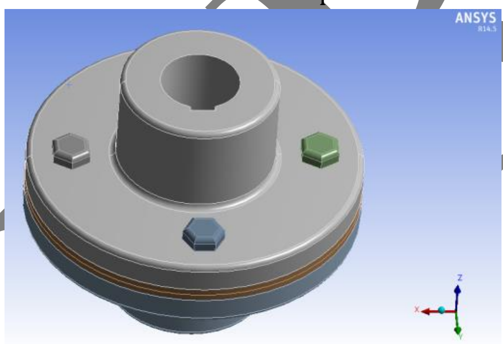


Fig.8: Flange coupling for FEA

A. MESHING:

The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. The finite element meshes for flange and bolt were created with the help of ANSYS tool which is a Mechanical meshing tool. Since the geometries of the flange and bolt models are complex, an unstructured Tetrahedron technique is used to mesh. The tool tries to create a mesh consisting of tetrahedron elements.

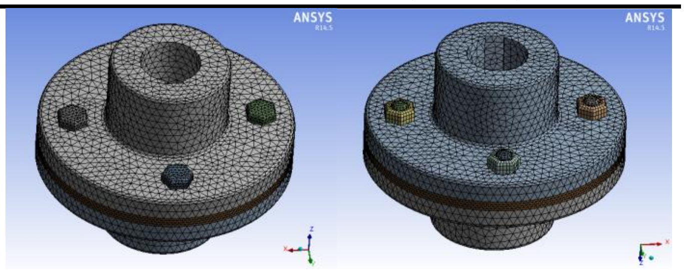


Fig.9: Meshing of flange coupling

TABLE II. MESHING DETAILS

Sr. No.	Parts	Elements	Number of Nodes/ number of Elements
1	Upper and Lower Flange	Higher order Tetrahedron	No. of nodes =90854 No. of Elements= 59059
2	Bolts and Nuts	Higher order Tetrahedron	No. of nodes= 23678 No. of Elements =12418
3	Gasket	Higher order Tetrahedron	No. of nodes= 109804 No. of Elements= 70644

B. MATERIAL ASSIGNMENTS:

Engineering data helps to define the material properties in the ANSYS. Once we input the properties, it can be assigned through mechanical to each of the parts. Following figure shows the input data entered in the project page of ANSYS mechanical.

C. LOADING AND BOUNDARY CONDITIONS:

Preload acting on the bolt would be applied on each bolt separately. The below images shows bolt pretension applied in the ANSYS. (1000 N preload is acting in each bolt after tightening the nut and bolts.)

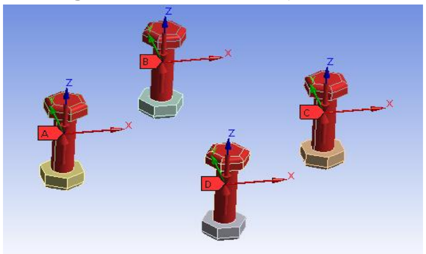


Fig. 10: Bolt Preload acting on the bolt

The internal fluid pressure will be applied on inner surface of the flanges and Gasket. The maximum pressure applied on assembly is shown in the below images.

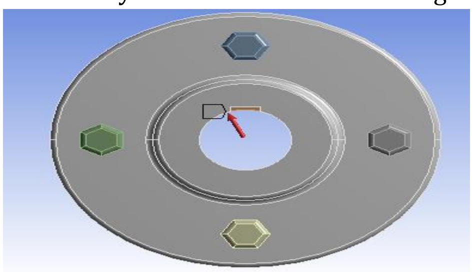


Fig.11: Internal Pressure acting on the inner surface

The all degrees of freedom of the gasketed coupling are fixed. The below images shows the surface where nodes are fixed in all diections.

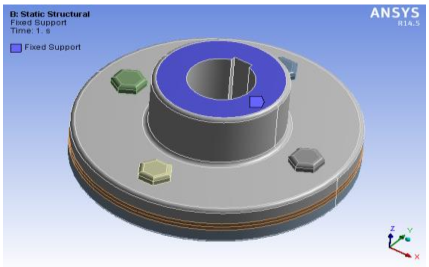


Fig.12: Fixed support applied on the coupling surface.

D. ANALYSIS RESULT:

RUBBER MATERIAL:

DEFLECTION PLOTS:

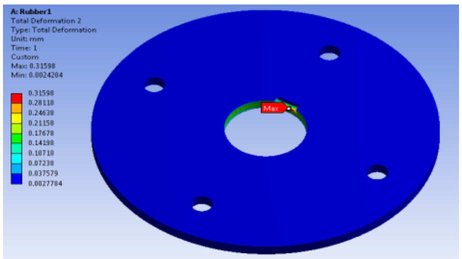


Fig.13(a): Deflection of Rubber Material Gasket

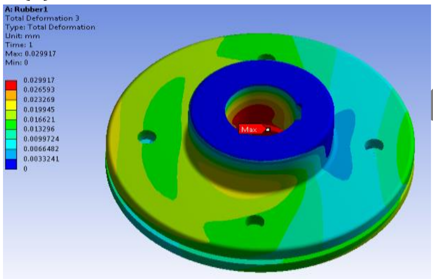


Fig.13(b): Deflection of flange having rubber material gasket

VON-MISES STRESS PLOTS:

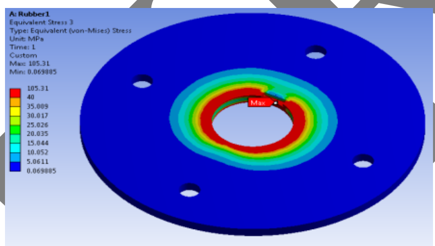


Fig.13(c): Von-Mises stress in rubber Gasket

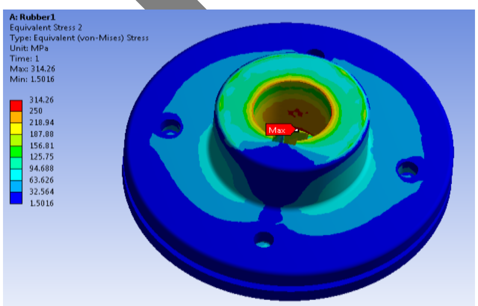


Fig.13(d): Von-Mises stress in Flange having rubber material gasket

NEOPRENE MATERIAL:

DEFLECTION PLOT:

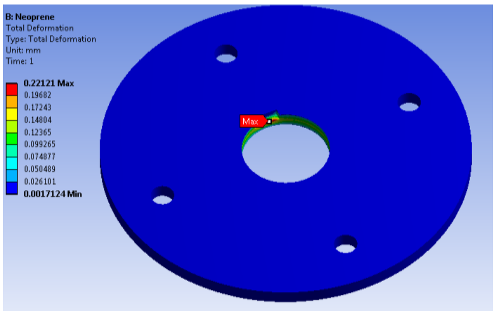


Fig.14(a): Deflection in Neoprene material Gasket

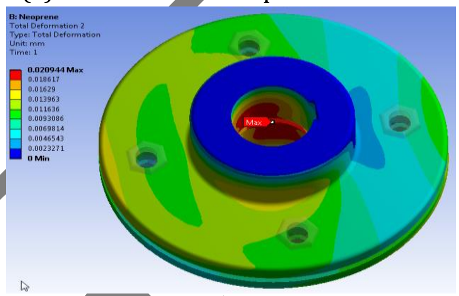


Fig.14(b): Deflection of flange having Neoprene material gasket

VON-MISES STRESS PLOTS:

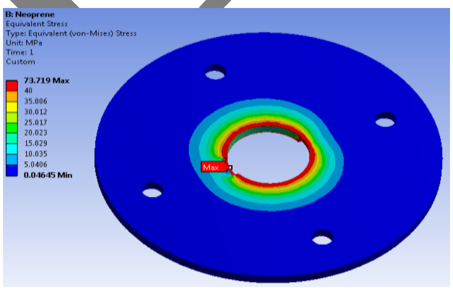


Fig.14(c): Von-Mises stress in Neoprene material gasket

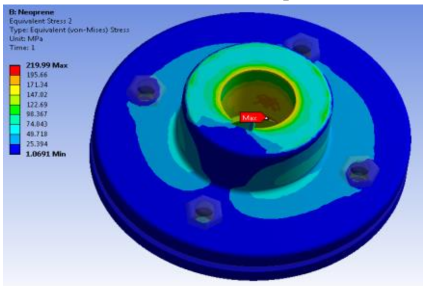


Fig.14(d): Von-Mises stress in flange having Neoprene rubber gasket

EPDM MATERIAL:

DEFLECTION PLOT:

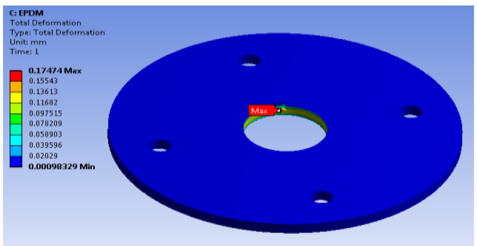


Fig.15(a): Deflection in EPDM material Gasket

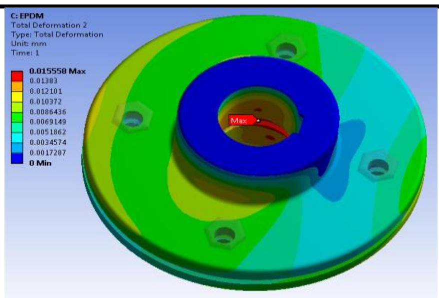


Fig.15(b): Deflection in flange having EPDM material Gasket

VON-MISES STRESS PLOTS

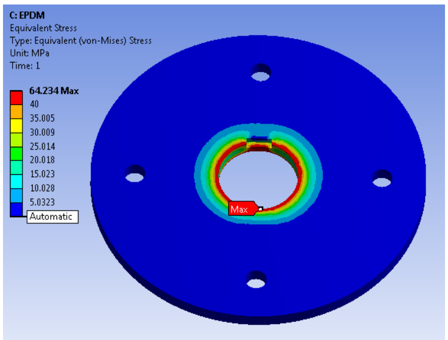


Fig.15(c): Von-Mises stress in EPDM material gasket

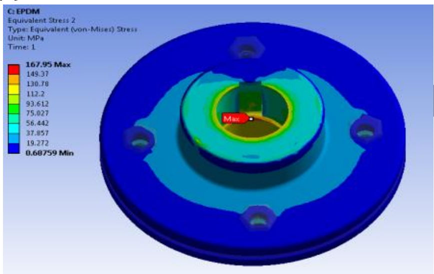


Fig.15(d): Von-Mises stress in flange having EPDM material gasket

IV. CONCLUSION:

The finite element analysis is carried out for different gasket materials. It is observed that, the rubber Gasket is subjected to maximum von –Mises stress up to 70 MPa. which exceed the yield strength of the material (Yield strength = 40 MPa). The second material Neoprene also shows von-Mises stress above the yield strength of material. Neoprene rubber shows von-mises stress upto 60 MPa. The EPDM is the best choice for the pipe application since, the von-Mises stress observed in EPDM is nearer to yield strength. While, the area under the maximum stress is less as compared to other materials. The current loading scenario does not show any failure in the gasket. So, EPDM is safe for our application. As per the FE analysis EPDM is the suitable material for the Application.

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