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Experimental Analysis & Optimization with Validation of Ball Valve Body of WCB Material

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Abstract: The ball valves are used in place of pipelines where the flow of fluid is needed. Ball valves have been mostly used for high temperature and high pressure valves which requires high quality products with confidentiality, reliability and durability. The ball has a bore or passage through the middle, so that when the port is in line with both ends of the valve, the flow of fluid will occur. When the valve is closed, the hole is perpendicular to the ends of the valve, and the flow is closed.

The ball valve can revolve 90°, which has large size and weight, but it has not only an enormously more excellent confidentiality than other valves in the severely high temperature and high pressure environment

When the ball valve is in closed condition the pressure exerted on the ball valve body due to that high pressure fatigue stresses and strain develop on the body of valve. Because of the high pressure and temperature on the ball valve body leakage of body take place which cause safety issue and ball valve failure. By this research stress strain analysis of ball valve body obtains and identifies the maximum and minimum stress and strain produced on the body of ball valve. The Max stress by parts was confirmed through thermal-structural coupled field analysis of major parts to evaluate safety. The objective of this research is to examine the effect of pressure and temperatures on valve components its analysis and optimization

I. INTRODUCTION

Selecting the proper valve for piping systems plays an important role in reducing the energy requirement and thus the operating cost. Various valves are used for on off control, modulation of the flow rate through the system, prevention of back flow and pressure relief as safety devices. One of the most widely used valves is ball valve. The primary aim of ball valve is to regulate the flow rate. The flow characteristics inside and downstream of the ball valves behave differently indifferent angle of valve and different inlet velocities. The valves are machine structures consisting of the housing and the sealing parts which are movable linearly or rotationally, perpendicular to the direction of fluid flow. They are used to regulate or to prevent fluid flow. Besides that, the contact area between the housing and the packing ring is too small and it leads to poor contact and fluid leakage. Numerous solutions are used nowadays to prevent leaking problem. The most common solution is to perform analysis and to improve the existing design. According to their function, the valves can be divided into: valves for regulation of flow or pressure, valves to block or redirect flow and the valves for load balancing. The valves can be made of carbon and alloyed steel, grey or alloyed cast iron and of other plastic or rubber materials. Ball valve housing has complex geometry with axial symmetry and they used to be manufactured by gravity casting. Gravity casting enables better surface quality and material properties and narrower tolerances than sand casting. This method is the best method for valve housing manufacturing. A ball valve is a form of quarter-turn valve which uses a hollow, perforated and pivoting ball to control flow through it. It is open when the ball's hole is in line with the flow and closed when it is pivoted 90-degrees by the valve handle.[1] The handle lies flat in alignment with the flow when open, and is perpendicular to it when closed, making for easy visual confirmation of the valve's status. Ball valves are durable, performing well after many cycles, and reliable, closing securely even after long periods of disuse. These qualities make them an excellent choice for shutoff and control applications, where they are often preferred to gates and globe valves, but they lack their fine control in throttling applications.

II. LITERATURE REVIEW

A. The Influence of Seat Fatigue Test on the Leakage in Ball Valve JanuszRogula

Paper presents the results of investigations of the ball valve tightness. The basic assumption needed to be verified was, whether the leakage through a seal after fatigue load will increase. The helium detector was used to determine the leakage volume in given time intervals. Very important assignment was to build a measuring facility which would enable leakage detection from the ball valve at helium overpressure range 0.1–4.5 MPa. Impact of the pressurized air on the closed ball was used as a fatigue factor. Impact could be used as a diagnostic procedure simulating exploitation conditions.

Gas escaping around the ball was measured when element was new, then after 5 000 and finally after 10 000 pressure impacts. Experiment included also similar leakage measurement through a stuffing box. On the basis of performed experiment, received research data and its analyze it is possible to forward following conclusions, application of mass spectrometry unit with helium as test gas occurs to be appropriate method when detecting leakage from ball valve. There is a strong relation between measured leakage rate and the working pressure of helium: by ball sealing leakage rate decreases with working pressure in range 0,1-3,1 MPa; it is a result of growing contact pressure between ball on PTFE ring surface through the gland packing leakage rate increases. Assembly load between ball and its seals is too small to protect before leakage in range of low pressure. Growth of assembly load makes the increase of open/close spindle torque. Fatigue test caused impressive change of tightness of ball sealing. Leakage was 4 or even 4.5 times bigger in pressure range 0.1–1 MPa. The main reason could be the growth of clearance between ball and seals. Difference after 5000 and 10 000 pressure impacts is much smaller, equal to 3-5 %. Decrease of the leakage is connected with the growth of contact pressure between ball and seal from the off-pressure side. After 5000 pressure impacts increase of leakage through stuffing box seals was visible. However it is difficult to give accurate numbers describing this change.

B. "Structural optimization for ball valve made of CF8M stainless steel" Xue-Guan SONG, Seung-Gyu KIM, Seok-Heum BAEK, Young-Chul PARK

In this research paper, the mechanical and chemical properties of CF8M were studied through experiments. An application of CF8M in valve body was analyzed by using finite element method (FEM) to evaluate the structural safety. An optimization containing several variables based on the response surface method was conducted to find the optimum dimension of the valve. The results show that using this process can save valve mass as well as the computational expense effectively. The ASTM A296 CF8M is very suitable to ball valve, because the chromium and molybdenum are added to enhance general corrosion resistance and to provide greater strength at room and elevated temperature.

By performing the optimization using orthogonalarray, response surface method and trade-off method, the mass of ball valve is reduced from 2.34 to 1.95 kg (16.67% from the initial design), while the maximum stress and pressure loss coefficient are still kept in the available range. The optimum design presented work does not consider temperature effect. Since this type ball valve may work at high temperature, it is necessary to include the thermal analysis in optimization in the future work.

C. "A Study on the Characteristic Analysis of High Pressure and High Temperature 3-Way Ball Valve" Si-Pom Kim, Rock-Won Jeon, Jae-Hun Lee, Jae-Hoon Lee and Seong-Jun Kim

This paper present research applied a numerical analysis method on thermal stress distribution and deformation, etc. In addition, the present research compared the performance test result with numerical analysis results. The Max stress by parts was confirmed through thermal-structural coupled field analysis of major parts to evaluate safety. And its performance was verified by carrying out the durability and leakage test for the manufactured valves. The present research verified design high pressure and temperature 3-way ball valves according to performed the thermal-structural coupled field analysis through analysis theories to grasp performance properties of a ball valve and obtained The finite element modeling was executed to make the high pressure and temperature 3-way ball valve for coincide with actual geometrical shape. The thermal-structural coupled field analysis and the performance test was carried out at 30kgf/cm2 (internal pressure of a ball valve), at-20℃ and at 230℃ (internal temperature). The maximum stress occurred at major parts of a valve was 317.59MPa and doesn't exceed 586MPa which is a range of allowable stress, and the maximum stress was referred to assess its stress analysis results.

D. "Experimental Residual Stress Analysis of Welded Ball Valve" Pavel Macura, Frantisek Fojtik, Radomir Hrncar

The paper is devoted to the issues of experimental analysis of residual stresses on the concrete part of pipelines – welded ball valve. A semi-destructive hole-drilling method was used for measurement, and experimental stress analysis and evaluation of residual stresses was made in accordance with the US standard ASTM E 837 – 01, as well as with use of an integral method. Residual stresses were measured both immediately after welding and after pressurizing of the ball valve. This has enabled observation of the influence of pressurizing on change of residual stresses in the neighborhood of the welded joint. Results of measurement of residual stresses served for further assessment of strength and service life of this component. The paper describes shortly the results of measurement of residual stresses in the welded ball valve. The aim of the measurement was to determine the magnitude of results after welding and to assess their influencing by the test pressurising. Process of pressurising is currently used forreduction of residual stresses; however, in those cases the applied pressures are much higher than in case of the measured ball valve.

E. "Weight optimization of 12"-150 class plug valve casting body by Finite Element Analysis" Pradnyawant .K. Parase, Prof. Laukik B. Raut

In this paper an attempt has made for weight optimization of plug valve body. Various models are created by changing the design parameters and analyzed these models for better results. . Results of finite element method for the structural analysis of the plug valve body are well in agreement with experimental results, as the deviation is maximum deviation is up to 9.75 % and minimum deviation is up to 6.23 % which is allowable.Results of decreasing the wall thickness and increasing the neck size are better than only reducing the wall thickness. The best optimized model is that, in which wall thickness is reduced by 2 mm and reduced wall thickness by 2 and increase neck radius to 180 mm, reduces 9.95 kg (7.11 %) weight, because maximum stress level is much lower than the yield stress value of the material.

F. Piyush P. Nagpurkar Investigated stresses developed in butterfly valve Shell and Disk.

This report contains the information about design and development for the 4'' X 150# Butterfly Valve with Double Eccentricity using ANSYS. It comprises the calculations which are required for design of Butterfly Valve such as Shell Thickness, Disc Thickness, Stem Diameter and Calculation of Torque using ASME, IBR. Also includes the modeling and assembly of butterfly valve using Pro-E. Finite Element Analysis of Butterfly valve Shell, Disc stem and their assembly is performed. The solid model will discretized into finite elements and logical constrains will applied in boundary conditions. The stress results obtained in finite element analysis will have to check whether, is there a chance for optimization of design. The analysis results shows that the Von Mises Stress induced in the parts of Butterfly Valve because of applied pressure of 20 bars, are less than the yield strength of the material. Hence finally concluded that, Design of Butterfly Valve for Chosen Material is safe.

G. "Optimization of Design of Butterfly Valve to Improve its Performance" by Girish B Pawar

[6] Discussed that as the valve's opening angle is increased from 0 degrees (fully closed) to 90 degrees (fully open), fluid is able to move readily flow past the valve. Studied problems during operation of Butterfly valve. The major problem related with Butterfly valve is Pressure drop and Flow loss. Pressure drop occurs when disc is rotated from fully closed condition to fully open condition (from 0 to 90 Degree by sub steps of 10Deg), cavitation takes place at downstream of flow at backside of disc. So, automatically Flow loss is increased and its performance is reduced. This problem can be reduced by giving various shapes (Aerodynamic) to the backside of disc.

Due to such design, fluid will easily flow over the disc. So, its performance can be improved. Major problem related with Butterfly valve is pressure drop and Flow loss. Pressure drop occurs when disc is rotated from fully closed condition to fully open condition (from 0^o to 90^o by sub steps of 10^o.) cavitation takes place at downstream of flow at backside of disc. For improvement in performance of Butterfly valve, there is need to reduce this problems. So these problems has reduced by giving various shapes (Aerodynamic) to the backside of the disc.

Due to such design, pressure drop is reduced and also there is increase in flow. Automatically it increases the performance of Butterfly valve.

H. "Weight optimization of the butterfly valve housing" Ejub Ajan [8].

Discussed that the basic methodology of butterfly–valve design by using CAD technologies and FEM. Main purpose is weight optimization of the valve housing body. Optimization of the complex shape constructions, such as the housing of the butterfly valve is successfully performed using CAE techniques. In this case, the valve housing (D = 600 mm and p = 16 bar) was optimized by reduction of the weight. New construction will be cheaper and more competitive at the market. In order to confirm these results, it is necessary to perform the experiment with these new values of thickness.

III. OBJECTIVES OF PROJECT

A. Study the ball valve design.
B. Select the appropriate material for testing and analysis.
C. Modeling and meshing of the component.
D. Finite element Analysis.
E. Validation of results with Experimental results.

IV. PROBLEM DEFINITION

At the time of hydraulic pressure exerted on the body of ball valve stresses and deformation occur on the surface of body. Due to the stress and deformation leakage of hydraulic fluid is occurs. Stress strain analysis require to evaluate the safety and its performance was verified by carrying out the durability and leakage test for the manufactured valves. So proposed work involves by taking all above parameters into consideration is to design a ball valve. It includes a plan to conduct experimental testing of valve to extract stress analysis on valve components with the help of suitable testing set up.

V. METHODOLOGY

A. *Step 1: Geometrical Data*

The geometrical parameters of a ball valve Body ID and Thickness, ball thickness, Stem Diameter etc will be taken to manufacture ball valve.

B. *Step 2: Material Data*

Various materials are available in market. Selection of material is very important criteria,
So material will be selected based on requirement, historical data and literature for valve components.

C. *Step 3: Modelling Of Ball Valve*

The CAD model is generated based on available geometrical data. Application of suitable loading and boundary condition is carried out to test and compare the observation.

D. *Step 4: Analysis Of Ball Valve*

The generated CAD model is analysed by applying proper boundary condition. The boundary condition is maintained suitable through the analysis. The load on valve is applied by considering practical situations. Thermal stresses, Pressure stresses, parametric effect of Thermal & Pressure stresses on valve body thickness, disc, stem etc. The available results are then compared with the experiments values.

VI. MATERIAL OF CONSTRUCTION

PART NAME	MATERIAL	TEMP ºC
Valve Body	WCC STEEL	-29 to 427
	CF8M,CF8,CF3M,CF3	-254 to 538
	LCC	-45 to 343
	WC9	-29 to 593
	CG8M,CG3M,CF8C	-254 to 538
Ball	WCC STEEL	-29 to 427
	CF8M,CF8,CF3M,CF3	-254 to 538
	CG8M,CG3M,CF8C	-254 to 538
Stem	STAINLESS STEEL SS-410	-254 to 538
	STAINLESS STEEL SS-316	-254 to 538
Seat	SOFT-PTFE	-62 to 232
	METAL-ALL	
Packing	PTFE V-RING	-254 to 232
	GRAPHITE ENVIRO-SEAL	-140 to 315

VII. MODELLING OF BALL VALVE COMPONENTS:

Material ASTM A216, Grade WCB

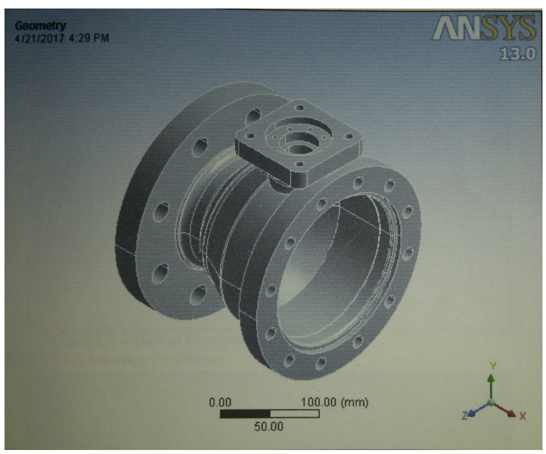
Physical Properties	Values	Values (SI units)
Ultimate tensile strength	70343.29 Psi	485 Mpa (N/mm^2)
Yield Strength	36259.43 Psi	250 Mpa (N/mm^2)
Allowable Stress	24173.43 Psi	166.67 Mpa (N/mm^2)
Young's Modulus (E)	2.9 X107	2.1X105 N/mm^2
Young's Modulus (E) at 150°C		1.95 X105 N/mm^2
Poisson's Ratio (μ)	0.3	0.3
Factor of Safety		1.5

A. Operating Conditions

Valve body is supported at one end
Internal area on valve body carries the pressure load =45 bar 94.5 N/mm^2)
Internal area of valve body has temperature 150°C
Outer surface of valve body has temperature 96°C

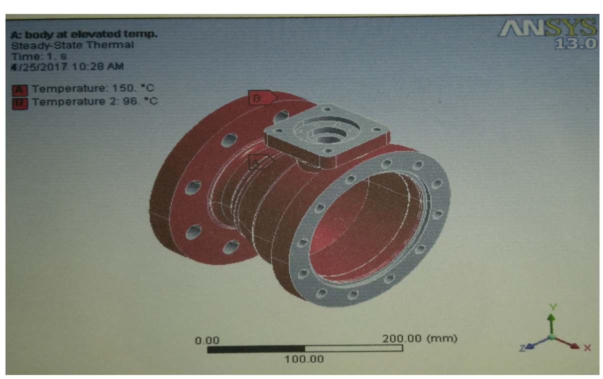
B. FEA Model

Analysis type: Thermal-Stress Analysis
Model Type: 3D Model

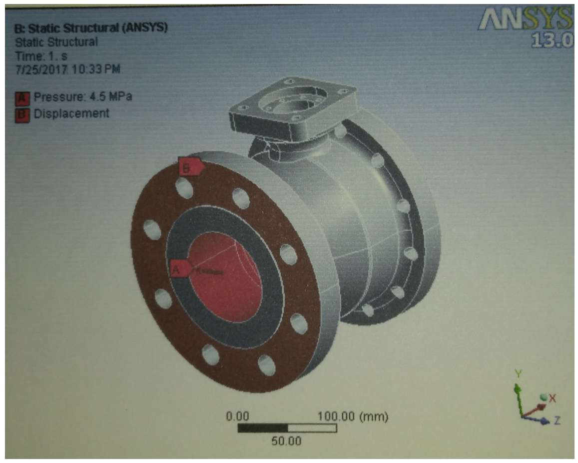


1) Boundary Conditions

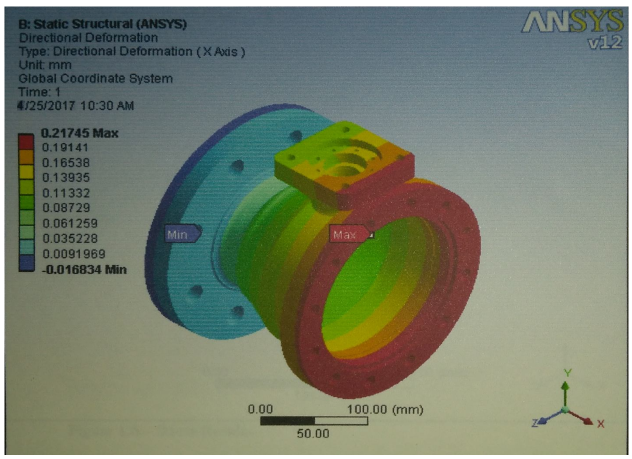
Thermal Boundary Conditions



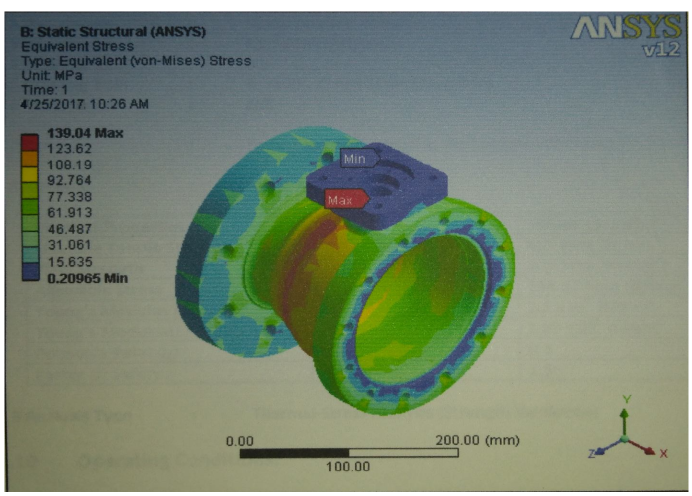
2) Structural Boundary Conditions



Deflection
Maximum directional deformation: 0.21745 mm



3) *Stress:* Von-mises Stresses: Following figure shows Von-mises stress distribution in the valve. Maximum stress found to be 139.04 Mpa.



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4) *Summary for structural Analysis*

	Max. value	Observation
Max. Axial Deformation	0.2174	Rigid Component
Max.Von Mises Stress (N/mm^2)	139.04	The maximum stress seems to be localized stress

Maximum stress induced in the valve body is 139.04 N/mm^2, which is less than the allowable stress of the material. So the valve body is safe to operate under the specified loading conditions.

C. Aim

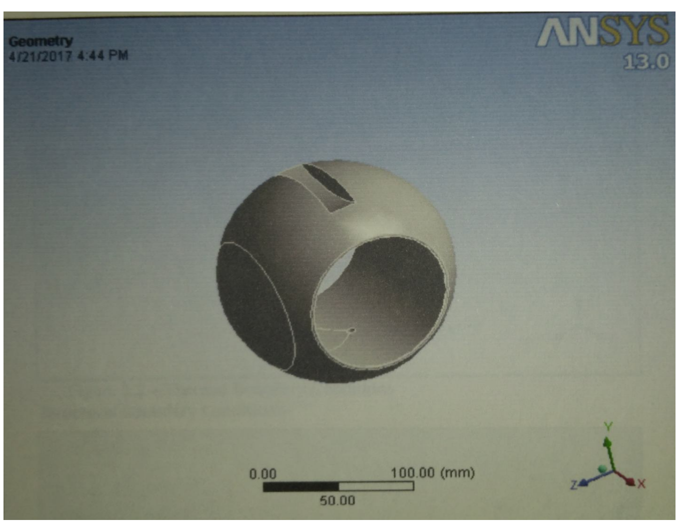
To find the maximum Stress in the component due to Pressure load of Ball

Material: ASTM A351 Grade CF8M

Physical Properties	Values	Values (SI units)
Ultimate tensile strength	70343.29 Psi	485 Mpa (N/mm^2)
Yield Strength	29732.73 Psi	205 Mpa (N/mm^2)
Allowable Stress	19822.30 Psi	136.67 Mpa (N/mm^2)
Young's Modulus (E)	---	2.1X105 N/mm^2
Young's Modulus (E) at 150°C	----	1.95 X105 N/mm^2
Poisson's Ratio (μ)	0.3	0.3
Factor of Safety		1.5

Analysis Type: Thermal-Stress Analysis (Strength Validation)
Operating Condition:
Ball is supported at both end
Circular area on ball carries the Pressure load= 45 bar (4.5 N/mm^2) Ball surface is exposed to 150°C.

1) *FEA Model*
a) *Analysis Type:* Thermal-Stress Analysis
b) *Model Type:* 3D Model



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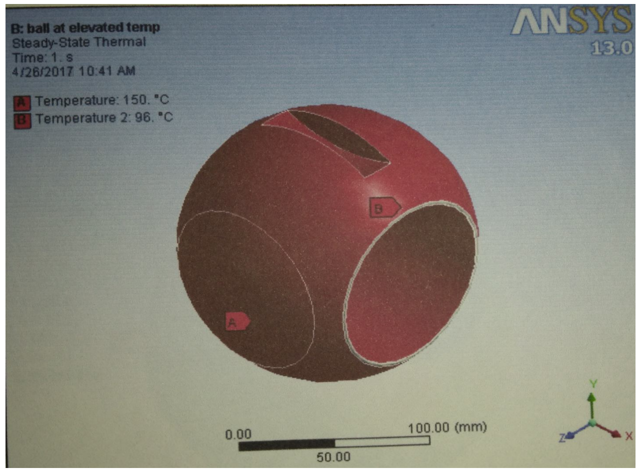
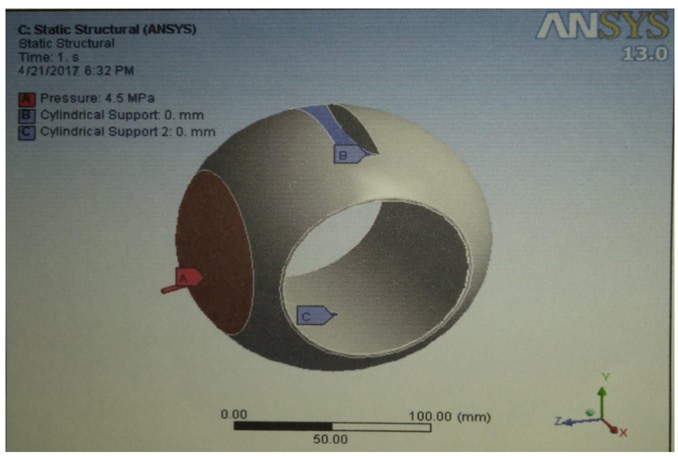
2) *Boundary Condition*

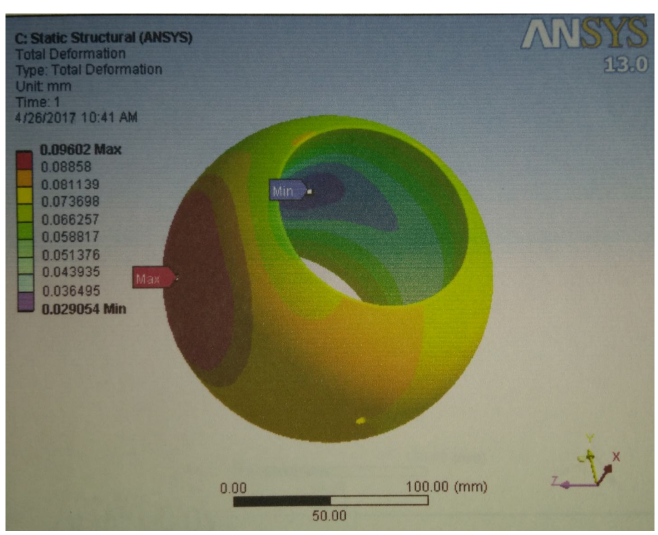
Thermal Boundary Condition



3) *Structural Boundary Condition*



4) *Deflection:* Max. Deflection = 0.09602 mm



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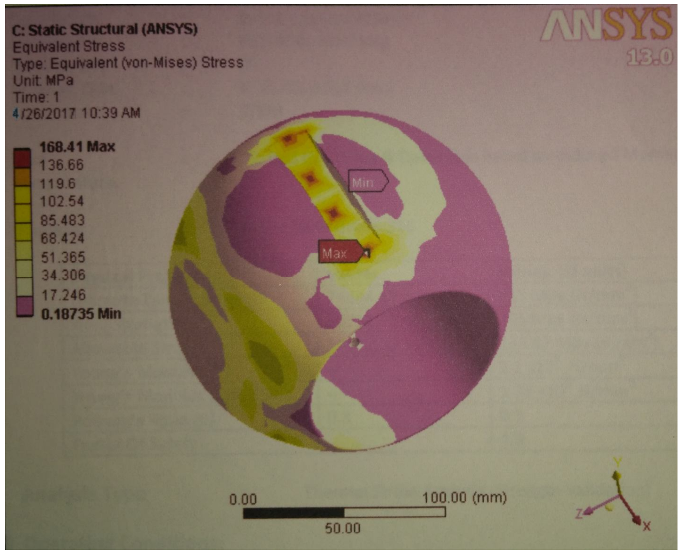
5) *Stress:* Von misses Stresses: Following figure shows Von-misses stress distribution in the ball. Maximum stress is found to be 168.41 Mpa



6) *Summary for Structural Analysis*

	Max. Value	Observation
Displacement (mm)	0.09602	Much rigid component
Von misses Stress (N/mm^2)	168.41	Max. induced stress is localized stress and average stress of Valve ball is below 136.66 N/mm^2 which is less than allowable stress limit of the material

Maximum stress induced in the component is 168.41 N/mm^2, it seems to be localized stress and average stress of the ball is 136.66 N/mm^2 which is less than the allowable stress of material. Also the deformation is 0.09602 mm. So it confirms the component is rigid and safe to operate under specified loading condition.

D. Analysis for Valve Stem

Material: ASTM A479 Grade 316
Analysis Type: Thermal Stress analysis (strength Validation)
Operating Conditions:
Cylindrical support on one side of stem
Flat surface on bottom of stem carries the moment load= 200 N.m= 200000 N.mm
Operating condition temperature: 150°C

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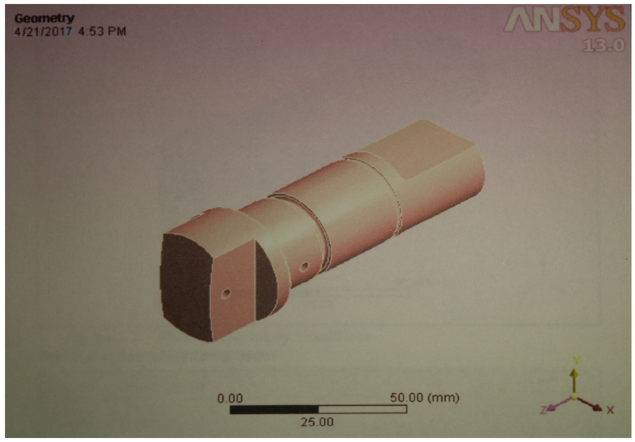
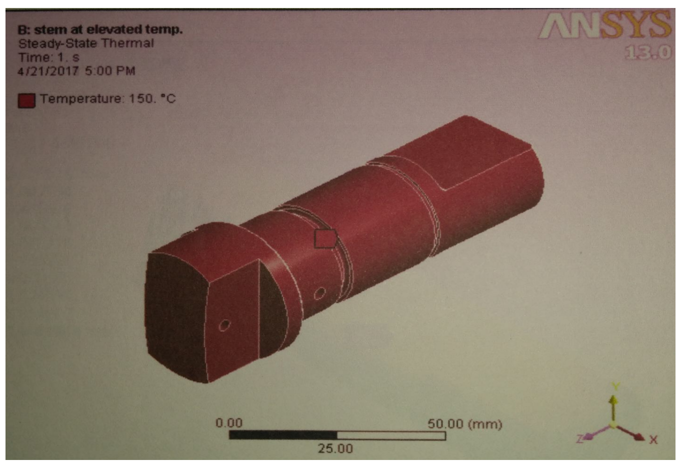
1) FEA Model

a) Analysis Type: Thermal-Stress Analysis.

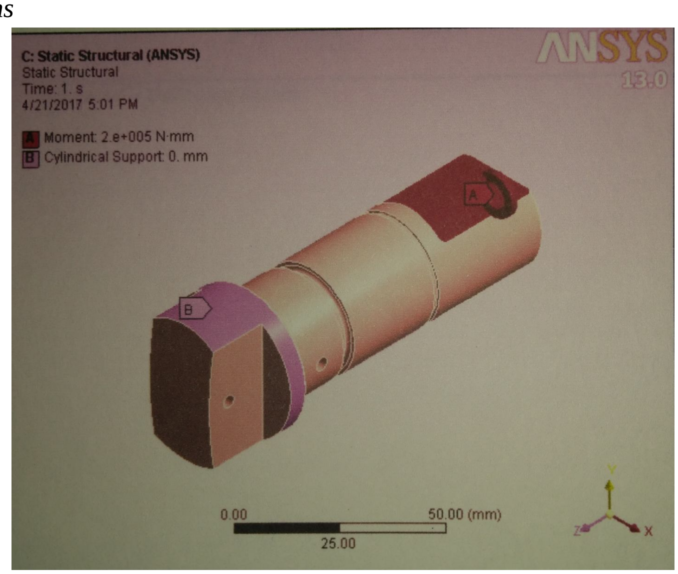
b) Model Type: 3D model



2) Thermal Boundary Condition

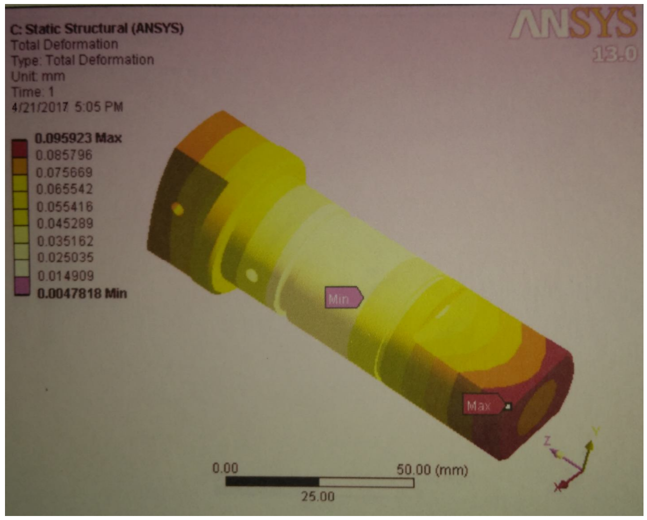


3) Structural Boundary Conditions

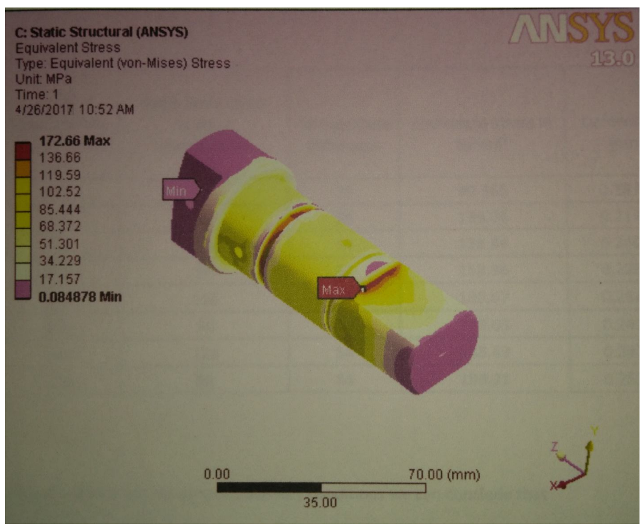


Deflection

Maximum Deflection: 0.095923 mm



4) *Stress:* Von-Mises Stresses: Following figure shows Von-Mises stress distribution in the stem. Maximum stress is found to be 172.66 Mpa at groove.



Results: Summary for Structural Analysis:

	Max. Value	Observations
Displacement (mm)	0.095923	Much rigid component
Von mises Stress (N/mm^2)	172.66	This maximum stress is localized stress caused due to stress concentration.
Average Von mises Stress (N/mm^2)	<136.66	Average stress induced in the component is less than136.66N/mm^2, shows component is under specified loading condition.

Maximum stress induced in the component is 172.66 N/mm^2, but as it is localized stresses so it can be neglected and average stress in component is below 136.66 N/mm^2 which is less than the allowable stress of the material. Also the deformation 0.095923 mm, so the component is safe to operate under specified load condition

VIII. CONCLUSION

A. *Stress-temperature Relationship*

For valve Body the relation between Stress and temperature is as follows:

Sr. No.	Valve Body Inner Surface Temperature in °C	Valve Body Outer Surface Temperature in °C	Temperature Difference	Equivalent Stress in N/mm^2	Deformation (mm)
1	125	96	29	90.365	0.18744
2	150	96	54	139.04	0.21745
3	160	106	54	138.84	0.24094
4	160	96	64	158.96	0.22945
5	170	116	54	138.67	0.26445
6	170	96	74	179.03	0.24146
7	180	126	54	138.49	0.28797
8	180	96	84	199.21	0.25348

After analyzing valve Body for various boundary condition we can conclude that
For constant temperature difference between outer and inner surface stress doesn't change considerable at higher temperature.
For 96 °C outer surface temperature, if we increase inner surface temperature, stress value increase considerably.
As from the summary of the result, we see that, the Von Mises Stress induced in the parts of Ball Valve because of applied pressure of 45 bars, are less than the yield strength of the material. Hence we conclude that, Design of Ball Valve for Chosen Material is safe.

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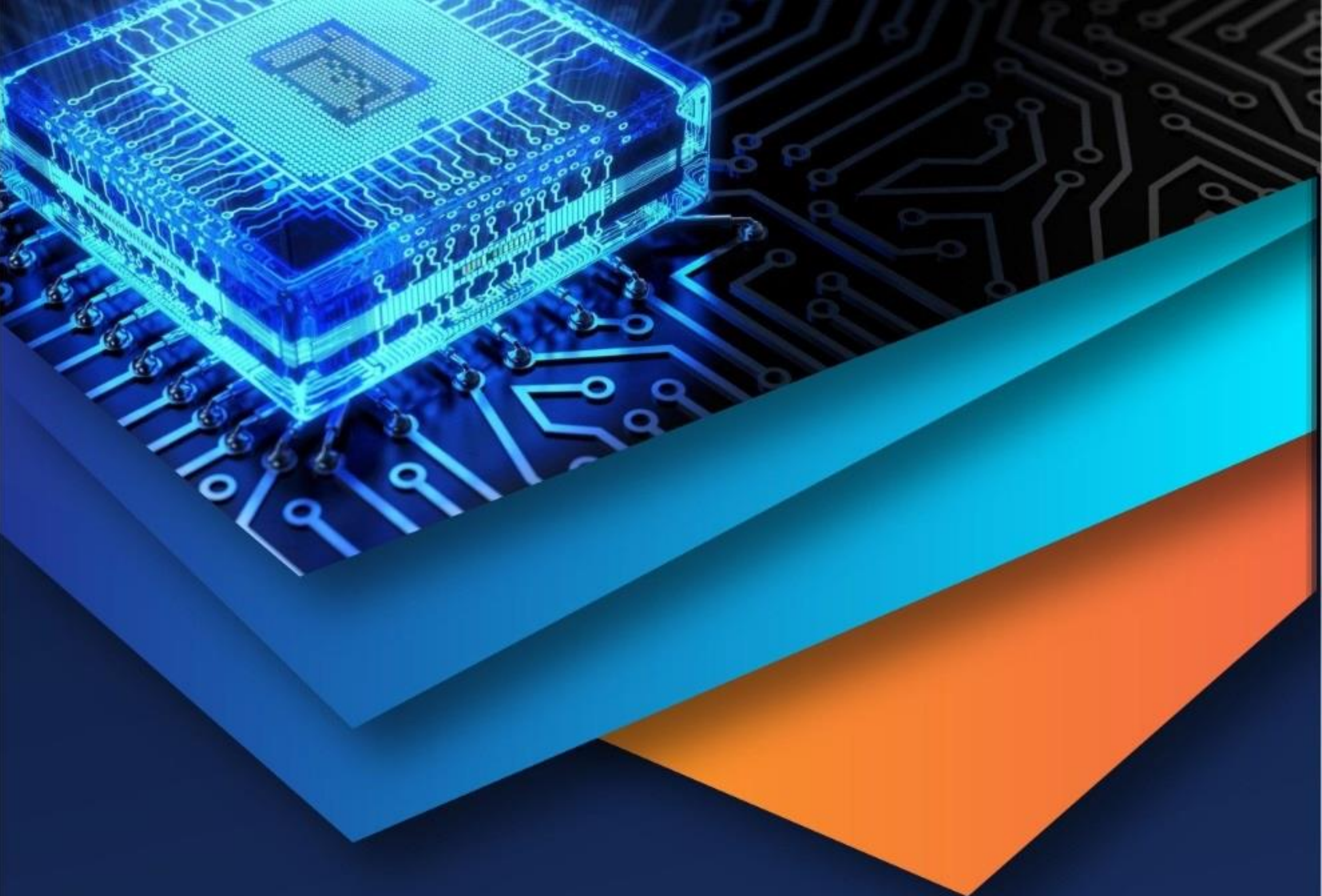
[4] Pavel Macura, Frantisek Fojtik, Radomir Hrncar "Experimental Residual Stress Analysis of Welded Ball Valve"
[5] Pradnyawant .K. Parase, Prof. Laukik B. Raut"Weight optimization of 12"-150 class plug valve casting body by Finite Element Analysis"
[6] Piyush P. Nagpurkar "Investigated stresses developed in butterfly valve Shell and Disk."
[7] Girish B Pawar "Optimisation of Design of Butterfly Valve to Improve its Performance"
[8] Ejub Ajan "Weight optimization of the butterfly valve housing"



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