Finite Element Analysis of Rupture Disc

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Abstract

With the advent of computers many of the critical components of Engineering are being designed successfully using Finite Element Analysis. The rupture disc used for safety in Chemical & Petro-Chemical Industries is one of the critical components where the design has to be done for failure of the material than the usual design problem of Engineering Design which is designing for strength. The present paper considers discs that fail because of Tensile stresses. An attempt has been made to study the possibility of designing rupture discs using Finite Element Analysis using ANSYS Software.

Introduction

It has been practice for many years to fit [1,2] thin diaphragms known as rupture discs in pressure equipment to provide a means of relieving excess pressure. The rupture discs are available in such materials of construction as Aluminium, Copper, SS316, Nickel 200, Monel etc and in different sizes. Previously the use of rupture disc was limited because of the apprehension of the reliability of the disc to open. With the advance of technology in design & Manufacturing of rupture discs the reliability of the discs has greatly improved. Also it is established fact that the use of rupture discs is made mandatory by the pressure vessel codes as the reliability of the disc has improved. With the increase in overpressure protection applications for rupture discs new designs with specialized physical properties have been developed and are also being developed. The rupture disc ensures safety of life and property in case of overpressure. A rupture disc (Fig 1) is a circular membrane clamped on the periphery which is designed to burst at a designated pressure. With protection by Rupture disc actuation is fast and is useful when large volumes of fluid has to be expelled quickly.

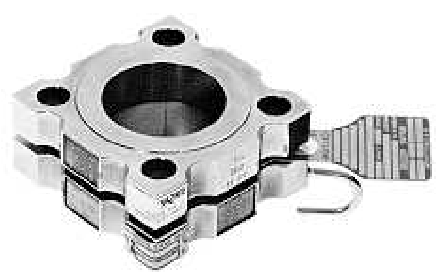

Fig 1: RUPTURE DISC BEFORE RUPTURE

Design

Traditionally the rupture disc design is based much on experimentation [3]. The rupture discs can be classified as tensional loaded discs, Compressive loaded discs and shear type that fail in pure shear. The present problem considers the tension loaded discs. In this case the disc is subjected to transverse load. From the point of application of load to the point of fracture the disc is supposed to pass three stages. In the first stage high stresses are induces. In the second stage the material is subjected to strain hardening and in the third stage formation of the bulge at the center and finally rupture takes place.

The burst pressure is dependent on such factors as material of construction, Disc diameter and Disc Thickness. The burst pressure can be calculated as [4]

$$P_b = \frac{UTS * t_0}{k * d}$$

From the above the burst pressure can be determined knowing the k factor.

As the load is applied the disc forms a spherical shape and the ability of the disc to carry load increases as because spherical, domed and ellipsoidal heads can withstand higher pressure than a flat plate. Thus geometric non-linearity [5] has been considered. Also since the material is subjected to strain hardening material non-linearity is considered.

Analysis

Modeling & Restraints

The rupture disc is modeled as a circular member clamped on the periphery and also a half of the model is considered , as it is symmetric. The above both cases have been analysed. In actual practice the rupture disc is mounted on the pressure vessel equipment to be safeguarded and hence the outer edge can be considered as clamped i.e fixed in all three rotations and three translations. In the second case since the disc is symmetric only a half of the model has been considered and the restraints applied as shown in Fig 2.

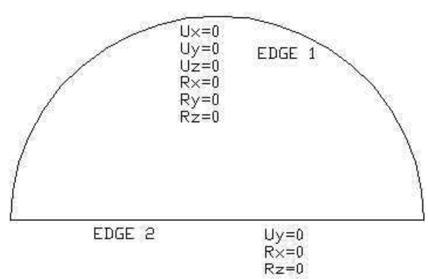

Fig 2: Restraints for the Symmetric Model

Loads

The load is applied as a pressure on the area. It has been applied as a constant pressure.

Elements

Since the disc forms hollow spherical shape as it is deflected the disc is modeled using the shell elements. The Elements considered are 4 node shell 43 for the case modeled as a whole and 4 node shell 181 for the case modeled as symmetric.

Material of Construction

The rupture disc is preferably made of ductile material. Several materials are available and the choice mainly depends on corrosion protection, burst Pressure and the application of rupture disc. The present analysis has been performed for the material copper 122 Annealed. The data sheet of this material [6] is given in Table 1. Table 2 gives the properties of the above material.

Table 1. Data Sheet of the Material

Copper ALLOY 122 (Known as Phosphorous De-oxidised Copper)	
Equivalent Alloy Specifications	
UNS	C12200
BS	C106
ISO	CU-DHP
JS	C12220
Composition: Copper Including Silver > 99.9% Phosphorous 0.015 – 0.040%	

Table 2. Properties of the above material.

Modulus of Elasticity	1.51E007 psi (1,04,137 Mpa)
Poisons Ratio	0.33
Shear Modulus	6.46E006 psi (44,551 Mpa)
Yield Stress	6700 psi (46.2 Mpa)
Ultimate Tensile Strength	31,300 psi (215.8 Mpa)

Fig 3 below shows the Stress – Strain Diagram [6] for the above material.

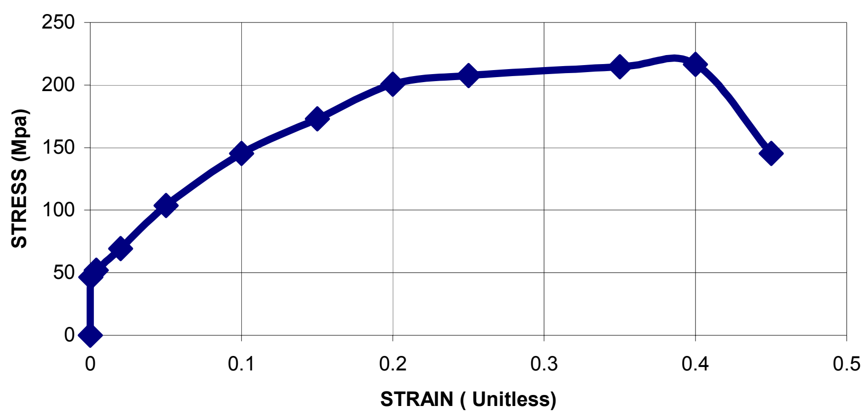

Fig 3. Stress - Strain Diagram

Meshing

The AutoMesh feature of the ANSYS software has been used. Linear Quadrilateral elements have been used.

Solution

The FE Model was solved for non-linear statics with Geometric Non-Linearity and Material Non – Linearity considered. Stress stiffening has been considered. The software used is ANSYS.

Others

Von – Mises Yield function is used. The hardening rule considered is Kinematic Hardening.

Results

Several Experiments were conducted by previous researchers and the value of K [4] for the above material is determined as 0.3. The present analysis is for a disc of diameter 6 inches (0.152 m) and thickness 0.040 inches (0.00101 m). The theoretical burst pressure determined with the above value of k is 695.5 psi (4.796 Mpa). The pressure determined from FEA is 591 psi (4.07 Mpa). Table 3 gives the summary of the results. Fig 4 gives the deflection Vs Pressure relationship. Brown & Sachs [7] determined the contour of the Annealed Electrolytic Copper Bulge with comparator. The bulging equipment consisted of a head supporting the die and an oil displacement cylinder capable of furnishing oil at pressures upto 3000 psi (20.68 Mpa). The bulging die had a 6 inches diameter circular opening in a 1 inch (0.0254 m) thick plate. Though the die opening considered in the experiment and FEA is 6 inches (0.152 m) there could be variation in die opening in the experiments because of the complication of the experiment involved. Fig 5 Shows the deflection Vs Distance from FEA and Fig 6 Shows the contour obtained by Brown & Sachs. The value of the Deflection at a distance of 2 inches (0.05 m) is 0.7 inches (0.0177 m) from Brown & Sachs and from FEA is 0.712 Inches (0.018 m). Fig 7 shows the analysis for the Symmetric Model and Fig 8 Shows the Analysis for the Whole Model.

Table 3.

LOAD CASE	LOAD Psi (Mpa)	DEFLECTION Inches (m)	Element Type
Symmetric Model	591 (4.07)	1.4155 (0.0359)	Shell 181
Whole Model	582 (4.02)	1.205 (0.0306)	Shell 43

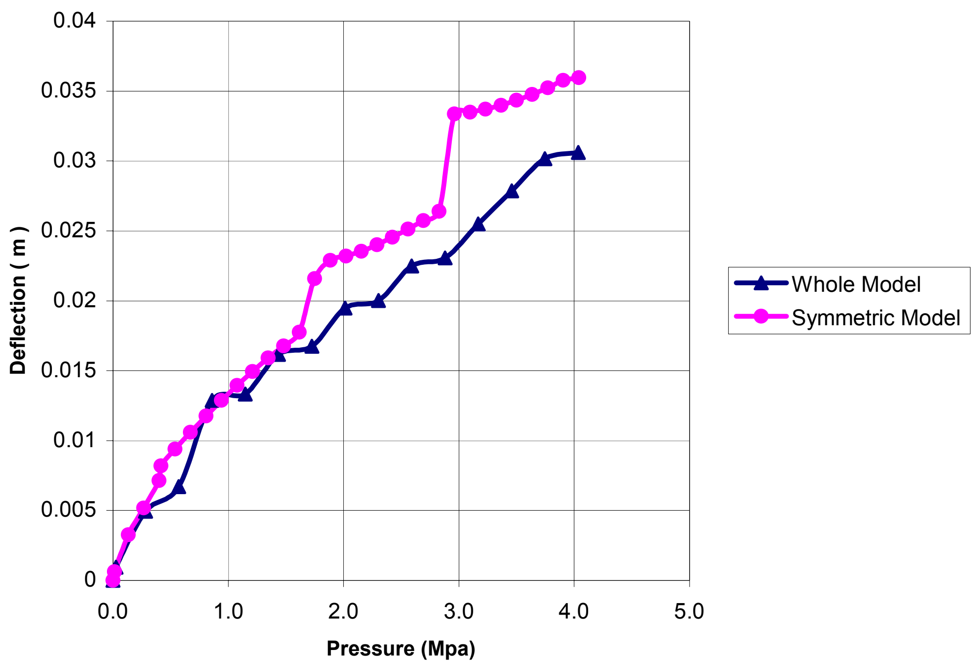

Fig 4. Deflection Vs Pressure Relation Ship

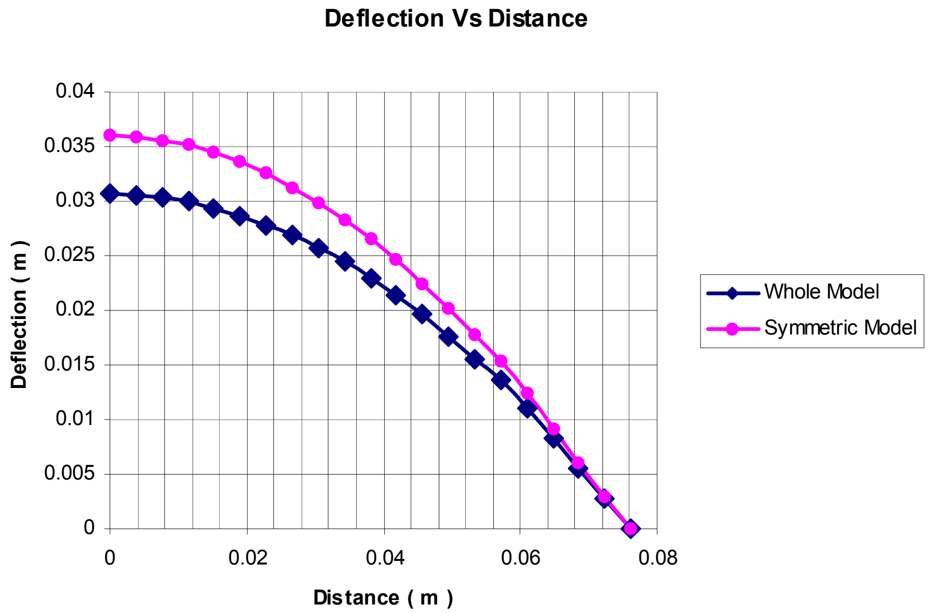

Fig 5. Deflection Vs Distance from FEA

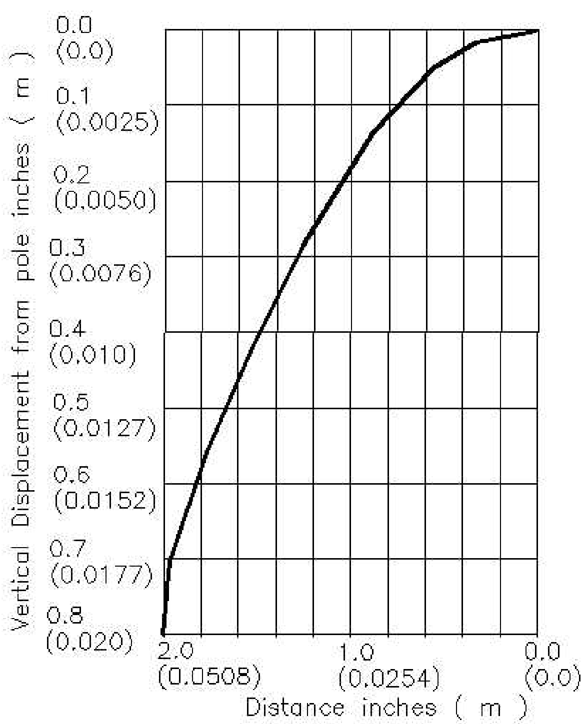

Fig 6. Contour obtained by Brown & Sachs[7]

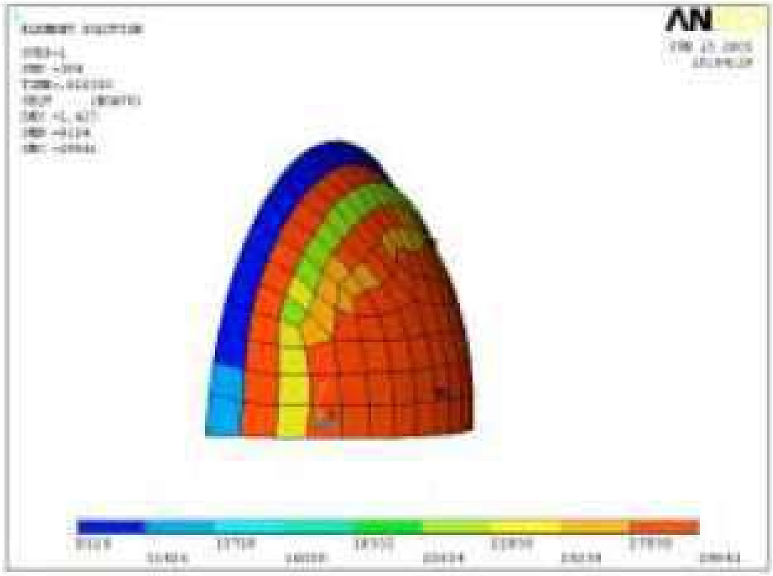

Fig 7. shows the analysis for the Symmetric Model

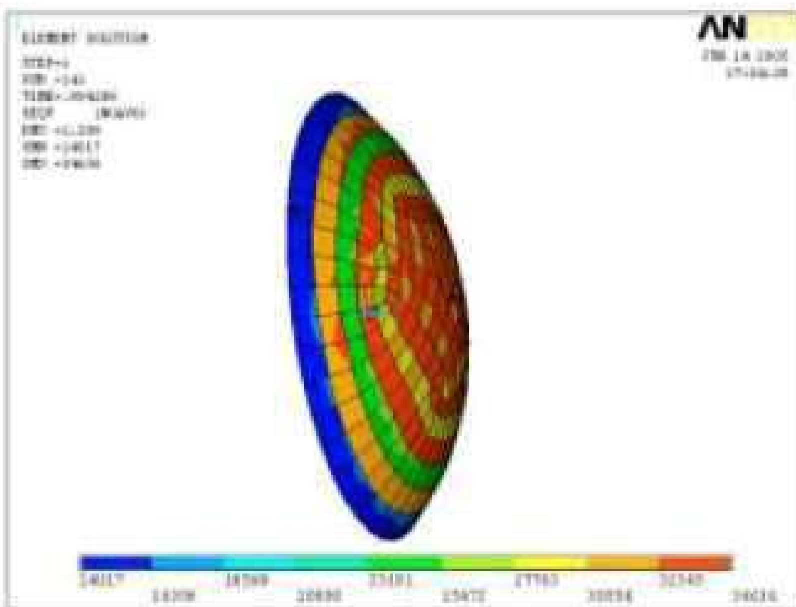

Fig 8. Shows the Analysis for the Whole Model

Conclusions

In this analysis the disc is subjected upto Ultimate tensile strength only and the studies have not been done upto fracture. It is seen that the calculated deflection value is in agreement with the experimental findings published. The difference in deflection & Pressure between the symmetric model and the Whole model could be due to the different type of elements used. The variation in Burst pressure is 15.02% with the published data. The difference might be due to the fact that the published data is upto burst pressure where as the FEA performed is upto UTS only. Further detailed studies have to be conducted before drawing any further conclusions.

Nomenclature

UTS	Ultimate Tensile Strength
d	Disc Diameter
k	Factor
P_b	Burst Pressure
t_o	Disc Thickness

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