

## FACTORS TO BE CONSIDERED FOR SELECTION & DESIGN OF RUPTURE DISC

**D V R Murty**

Scientist EI, Design & Engineering Division, IICT, AP, India 500 007

**A ChennakeshavaReddy,**

Assoc. Prof., Dept of Mech. Engg., JNTU, India

**Y Bhaskar Rao,**

Scientist F, Design. & Engineering Division, IICT, AP, India 500 007

### ABSTRACT

All over the world numerous fatalities and large property losses have taken place because of Industrial Explosions. In order to mitigate the losses of life and property due to overpressure rupture discs are used. Successful implementation would depend on many factors and one of the important factors is the selection and design of rupture discs. There are several factors that affect the disc performance. The present paper discusses the factors that effect the disc performance so that the right type of disc can be selected.

**Keywords:** Rupture disc, Bursting Disc, Materials

### 1.0 INTRODUCTION

Rupture discs are frequently used to prevent pressure in components of Chemical & Petro-Chemical, Nuclear plants from reaching a dangerous value. The consequences of such a failure as overpressure can lead to hazard of flying fragments in the event of a burst in addition to release of toxic, flammable and highly hazardous fluid leading to loss of life, property and environmental degradation. Because of the above reasons pressure vessel codes have made it mandatory to use protective devices such as safety valves and rupture discs. With protection by rupture disc ( Fig 1: ) actuation is fast and is particularly useful when large volumes of fluid have to be expelled quickly [1]. There are different types of rupture discs such as (a) Plain Diaphragm Type (b) Cross cut diaphragm type (c) The shear type.

### 2.0 SELECTION

The burst pressure is defined as the pressure at which the disc fails and bursts or opens relieving the excess pressure. The most important parameter to specify rupture disc is the burst pressure. The burst pressure and thereby the selection of rupture disc is

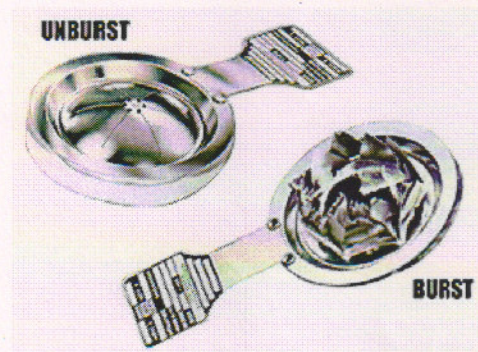


Fig 1: Rupture Disc

influenced by such factors as Material of Construction, Disc Diameter, Disc Thickness, Temperature and Pressure.

### 2.1 MATERIAL OF CONSTRUCTION

The MOC of a rupture disc is important from the point of view of design & manufacturing and also from the standpoint of corrosion. From the view of Design & Manufacturing the essential properties required for the material that the rupture disc is made of are

- Low Strength so that discs of practical thickness may be employed
- Availability as thin sheet and strip
- High ductility for discs of Plain Diaphragm type
- Low Creep under stress close to Ultimate Tensile Strength

During the earlier days of Industrial revolution the equipment were subjected to low pressures. Because of the inherent design and low burst pressure

requirement the choice of material was limited to metals such as Aluminium, Copper, Brass, Silver etc. With the development of Science and Technology the equipment is being subjected to high & Ultra- high pressures. Also several Chemical processes have demanded the requirement of new construction materials. Thus the choice has extended from very ductile materials to SS316, Nickel, Monel, Titanium, and Plastics etc. The available materials of construction can be broadly classified as Metals, Plastics/Composite, and Graphite [2-4].

### 2.1.1 METALS

Solid prebulged metal discs are the basic foundation for most rupture disc designs. When the disc is pressurized the disc forms a spherical shape. The disc then yields plastically getting progressively thinner from the clamping surface to the center of the disc leading to rupture. The low tensile strength of materials such as Lead and Tin appear to be attractive for bursting disc but actually their use is not recommended. Lead has poor creep resistance and also poor fatigue resistance and can cause untimely failure. Tin also has extremely poor resistance to creep and thus is unsuitable. The choice of a suitable material is also influenced by the ratio of working pressure to bursting pressure. The ratio of working pressure to bursting pressure for different materials is available in literature. Solid metal disc of Aluminium, SS316, Nickel, Monel, Silver are commonly used. Less frequently used metals include Tantalum, Platinum, Gold, Titanium and Hastelloy B & C.

### 2.1.2 PLASTICS/COMPOSITE

These are fabricated of two or more members to control the rupture pressure. The advantage of the composite disc over the solid disc is that

- Reduces the bursting strength by a factor of 10. When the composite disc is used with a relatively weak nonmetallic material seal, lower rupture pressures are obtained for a given disc size.
- Prevents disc fragmentation during disc rupture.
- Improves corrosion resistance by using exotic materials as seal membrane

The plastics have corrosion resistance to many chemicals and many different types of plastics are available.

### 2.1.3 GRAPHITE

The characteristics of graphite rupture discs are

- Temperature resistance below 300 °F and can be used for temperatures exceeding 600 °F
- Thermo shock resistant
- Easily manufactured to any rupture pressure
- Fragmentation

- Commonly used coatings and linings are Fluorocarbon, Polyethylene, Epoxy, Vinyl and Lead
- This has corrosion resistance to many chemicals

From the corrosion point of view there are several materials and a suitable material can be selected. In any case if a suitable material is not found then a safety valve / rupture disc combination can be used [5].

## 2.2 DISC DIAMETER & THICKNESS

In the plain diaphragm type of disc where in the disc fails by induced tensile stresses the burst pressure is given [6] by

$$P_b = \frac{UTS \times t_o}{k \times d} \quad \text{Equation (1)}$$

For a given material of construction we have

$$P_b = (\text{constant}) \times \frac{t_o}{d} \quad \text{Equation (2)}$$

Thus it can be seen that bursting pressure is proportional to  $(t_o/d)$ . As  $t_o$  is smaller we get small burst pressures but thickness below a certain minimum are impossible to be formed. As  $d$  is increased we get smaller burst pressures and as  $d$  is decreased we get larger pressures and for the same pressure we can use smaller  $d$  and larger  $t_o$ . But the diameter ( $d$ ) of the rupture disc opening is dictated by the adequate relieving capacity to release fluid at a sufficient rate to prevent any buildup of pressure in the vessel to which the disc is attached.

## 2.3 PRESSURE

If the disc is subjected to high pressure than burst pressure for a larger period of time then excessive creep may take place and ultimately burst at a pressure far below the designated pressure. The performance of the disc depends on whether the pressure is static or surging. System operating conditions as positive pressure (+) or Vacuum (-), Constant Vacuum or alternating pressure and Vacuum. Rupture discs give good service life when operated at 80% or less of the rated pressure. Rupture disc designed to be installed with the pressure medium against concave side of the disc dome require a support member to prevent flexing of the disc during Vacuum or backpressure conditions. The Vacuum support is designed for 15 psig backpressure service. The Vacuum support must be a near perfect fit with the concave side of the disc to prevent even slight reverse flexing which leads to premature bursting.

## 2.4 TEMPERATURE

Rupture disc temperature is a critical parameter because in most instances the disc is installed at the end of a stagnant piping section. Actual disc temperature may be significantly different than the system temperature due to heat loss from fluid. The lowest expected temperature such as ambient temperature could be specified if the disc discharges to the atmosphere. This way since the disc is at a higher temperature it will fail at a lower safe pressure. The effect of temperature on the disc rupture pressure depends on the construction material. The disc material has a specific strength versus temperature relationship. Fig 2: shows the relationship of strength versus temperature for the material Copper 10% cold drawn [7]. The solid metal disc pressure rating decreases rapidly with increase in disc temperature. Also the

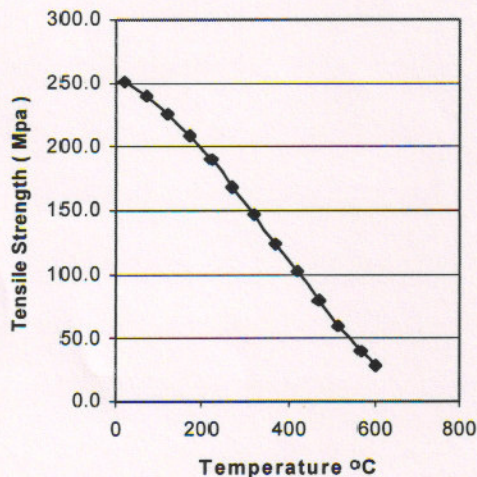


Fig 2: Tensile Strength Vs Temperature

Stress-strain curve (i.e strain hardening) is dependent on temperature. Inconel exhibits less disc rating change over the normal operating temperature range than stainless steel.

## 2.5 OTHERS

It is important that the precise metallurgical condition of the piece of metal actually used is known. The properties of the material depend on the heat treatment done. Thus a material of Annealed condition will have different properties than of the same material cold worked / hot worked. Also the properties of the material are different for different grain structures. Fig 3: shows the stress strain curve for 3.4 micron grain size [7].

## 3.0 DESIGN

Most of the Engineering components are designed for strength where as the rupture disc is to be designed for failure. The design of most of the Engineering components involves structural analysis using linear formulation where as the rupture disc requires non linear analysis. Several researchers have

performed detail experiments [6,8] varying disc diameter, disc thickness, temperature and material of construction. Most of the design of rupture disc is based on experimentation. Though this method is sound it involves huge cost since actual bursting discs are burst to determine the burst pressure. An attempt has been made here to perform Finite Element Analysis of rupture discs. In carrying out a Finite Element Analysis of rupture discs the following aspects should be considered.

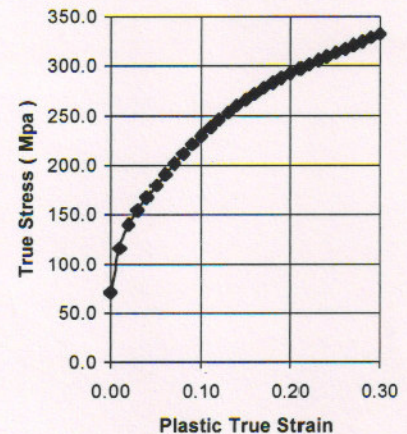


Fig 3: Stress Strain Curve of Copper for 3.4 Micron Grain Size

- Material Non-Linearity:** The rupture disc as the pressure is increased, is stressed beyond the yield point and hence it is subjected to strain hardening. This represents the region of plastic deformation and has to be taken into consideration.
- Geometric Non-linearity:** As the load is increased on rupture disc the disc assumes a spherical shape. As the configuration changes to spherical segment the ability of the disc to carry load increases as domed, ellipsoidal withstand more load than a plate of same thickness. Also the deflection is high as it is in the plastic deformation state. This necessitates the geometric non-linearity to be considered. Also the structure stiffness must be recalculated in its updated state.
- Creep:** In practice the rupture discs are kept installed on the equipment which are intended to be safe for over years. This subjecting of the disc for a long period to the working pressure causes creep. Thus the combined effect of material non-linearity, geometric non-linearity, creep and fracture have to be considered in the analysis of rupture disc.

Analysis has been performed considering the combined effect of material non-linearity ( plasticity ) and geometric non-linearity. In the analysis the disc is

modeled as a circular section. The disc is considered to be clamped on the edge. It is subjected to Transverse load ( pressure). The disc is modeled using thin shell elements. Equation (1) [6] gives the variation of burst pressure with thickness for a given value of K and Ultimate tensile strength. The value of k for Nickel is given as 0.3 [6] at room temperature. Fig 4: shows the Bursting pressure Vs Thickness for Nickel Reproduced [8] and these are

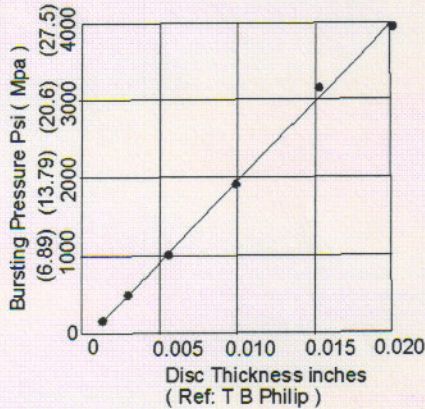
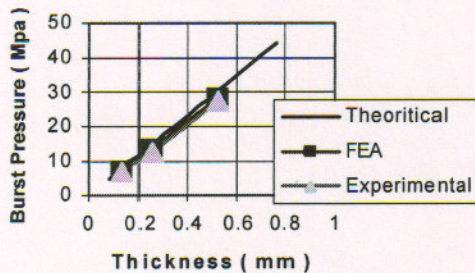


Fig 4: Bursting Pressure Vs Thickness for Nickel Reproduced ( T B Philip )

experimental values. Fig 5: shows the comparison of burst pressures between theoretical [ 6], Finite element analysis and experimental [8]. Figure 6 shows the



Disc Diameter 25.4 mm; Material of Construction - Nickel

Fig 5: Comparison of Burst Pressures

deflection Vs Applied pressure reproduced [8]. Fig 7: shows the deflection Vs Load obtained from Finite Element Analysis. Figure 8: shows the induced stress variation with distance ( Radius ) for a load of 5.49 Mpa and. Fig 9: shows the deflection Vs Distance (radius) from FEA.. Fig 10: shows Mises Stress by ANSYS.

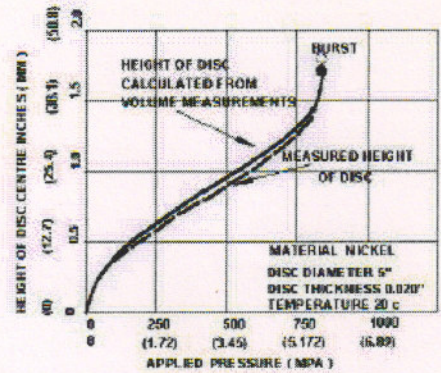


Fig 6: Deflection Vs Applied Pressure for Nickel Reproduced ( T B Philip )

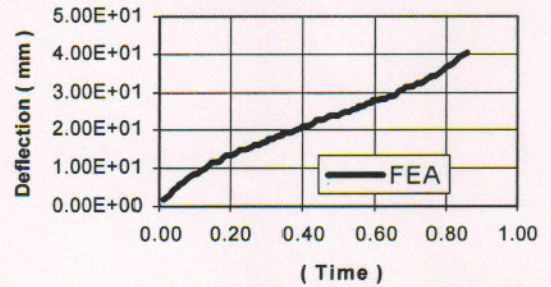


Fig 7: Deflection Vs Time ( Load ) for Disc Diameter 127 mm and Thickness 0f 0.508 mm

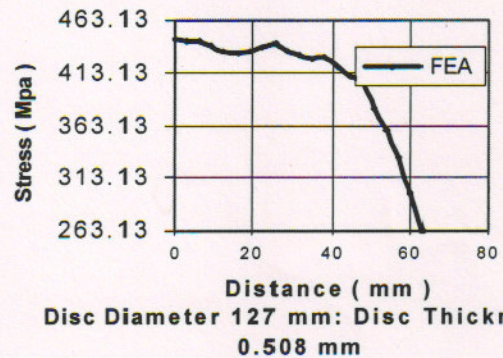
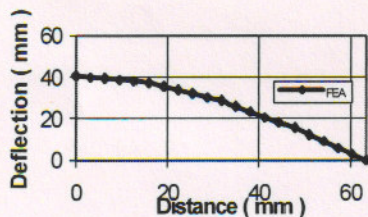


Fig 8: Induced Stress Vs Distance ( Radius ) at a Load of 5.49 Mpa for Disc Diamter of 127 mm and Disc thickness of 0.508 mm



Disc Diameter 127 mm: Disc Thickness 0.508 mm

Fig 9: Deflection Vs Distance ( Radius )

Table I gives the summary of the results for disc diameter of 25.4 mm and Nickel as material of construction. Table II gives the maximum percentage variation. Table III gives the results for disc diameter of 127 mm and MOC Nickel. Table IV gives the maximum percentage variation. It can be seen from Table I & II and from Fig 4 & 5: that the burst pressure from FEA are in close agreement. It can be seen from Fig 6: that the burst pressure is ( approximately ) 5.793 Mpa. The maximum Deflection is ( Approx. ) 45.72 mm Fig 7: is a plot of deflection Vs Time from FEA. Here the load is directly proportional to time. Time 0 corresponds to 0 Mpa and time 0.85524 corresponds to 5.49 Mpa. The maximum deflection is 40.5 mm. Thus these are in good agreement with values from Fig 6:. Also the striking point is the match of pattern of the curve in Fig 6 & Fig 7. It can be seen from Fig 9: that the deflection is maximum at the center of the disc with a value of 40.5 mm and zero at the edge of the disc.

#### 4.0 CONCLUSIONS

In the design & Installation of rupture discs the selection of rupture discs is one of the critical steps. The present paper discusses the different factors to be considered for selection and design of a right type of rupture disc for the intended application. An attempt has been made to design rupture discs and the aspects that have to be considered for design using Finite Element analysis. In addition to the determination of burst pressure by experimentation by incorporating the design of rupture discs by FEA it may be possible to reduce the lot size ( Sample size ) that is agreed between the manufacturer and customer. Further work needs to be carried out wherein the

design has to be done by combining the Geometric-non-linearity, material non-linearity ( I.e: Plasticity & Creep ) and Fracture and for different materials of construction and for different temperatures.

#### 5.0 NOMENCLATURE

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

#### 6.0 REFERENCES:

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TABLE I ( Summary of Results )				
Disc Diameter 25.4 mm ( 1" ); Material of Construction ( MOC); Nickel				
Disc Thickness ( inches)	Disc Thickness (mm)	Theoretical ( Mpa )	FEA ( Mpa )	Experimental ( Mpa )
0.0054	0.137	7.984	7.42	6.90
0.01	0.254	14.78	13.71	12.75
0.0206	0.523	30.457	28,26	27.241

TABLE II ( Maximum Percentage Variation )			
Disc Diameter 25.4 mm ( 1" ); MOC: Nickel			
Thickness ( mm )	Theoretical / FEA	FEA / Experimental	Theoretical/ Experimental
0.137	7.06	7.0	13.52
0.254	7.23	7.0	13.73
0.523	7.19	3.6	10.5

TABLE III			
Disc Diameter 127 mm ( 5" ); MOC: Nickel			
Thickness inches ( mm )	Theoretical psi (Mpa )	FEA psi (Mpa )	Experimental psi ( Mpa )
0.020 ( 0.508 )	857 ( 5.91 )	796 ( 5.49 )	840 ( 5.793 )

TABLE IV ( Maximum Percentage Variation )			
Disc Diameter 127 mm ( 5" ); MOC : Nickel			
Thickness inches ( mm )	Theoretical/FEA	FEA/Experimental	Theoretical/Experimental
0.020 ( 0.508 )	7.1	5.17	1.86

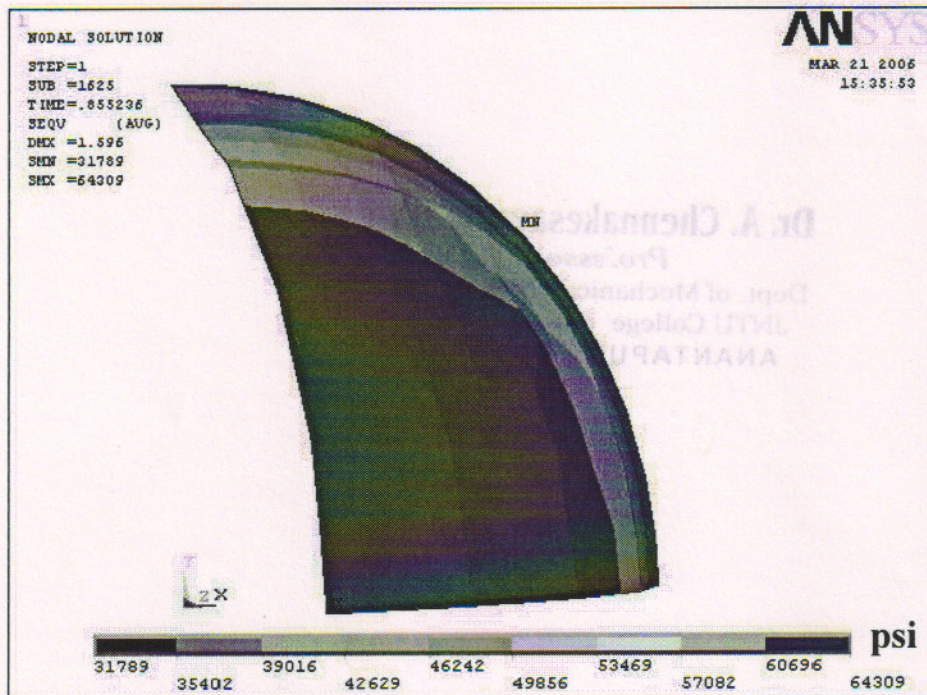


Fig 10: Mises Stress by ANSYS