FINITE ELEMENT BASED COMPUTATIONAL STUDY FOR ASSESSMENT OF ELASTIC FOLLOW-UP IN AUTOCLAVE PRESSURE VESSEL

Phool Singh Dinkar[1], Sushovan Chatterjee[2]

[1]*M.Tech. Scholar, Department of Mechanical Engineering, N.I.T, Silchar (India)*

[2]*Assistant Professor, Department of Mechanical Engineering, N.I.T, Silchar (India)*

ABSTRACT

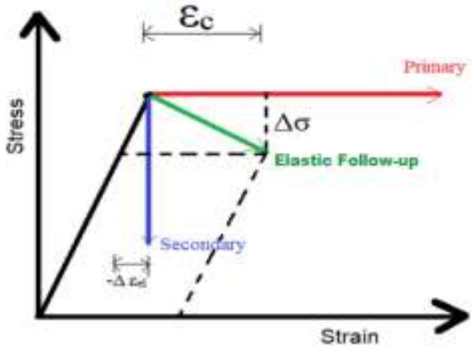
Elastic follow-up is a complex and very influencing phenomenon in pressure vessel and piping system. It affects the performance of some structural components. Quantifying of elastic follow-up value is not that much easy, because it's still not clearly defined in ASME power piping code book. In this paper, elastic follow-up phenomenon in a laboratory based autoclave pressure vessel is shown in detailed analysis manner and brief reviews about previous research paper have been discussed. Geometric modeling of autoclave pressure vessel carried out by Creo2.0 and for analysis purpose Finite element based ANSYS14.0 software is used. Reduced elastic modulus method is used to quantify elastic follow-up. Here a study of elastic follow-up phenomenon taken into consideration at various temperature and pressure with varying elastic modulus but constant geometric parameter. Stress concentration and its effect on elastic follow-up have been described.

Keywords*: *Elastic Follow-up, Finite Element Analysis, Stress concentration.

I. INTRODUCTION

The term follow-up elasticity was first used by Robinson [1] in 1955, later known as elastic follow-up. In fig.1 it can be seen that as creep strain increment exceeds the elastic strain decrease and due to this Elastic follow-up factor is present. Elastic follow-up factor increases as relaxation progresses. Rate of relaxation of residual stresses is found to be proportional to the elastic follow-up factor (Z). It is a concept used to test the importance of possible inelastic strain concentration in a piping system designed primarily using the elastic rules specified in the ASME boiler and pressure vessel code [2]. Elastic follow-up also occur when reduction of modulus (due to stress decreases with increase in strain) is there [3].

Smith et al. [4] carried out experimental work on a bar assembly, which was fixed at both ends and subjected to total load in the central bar. Outer bar remains elastic whereas central bar undergoes perfectly plastic deformation. The load will be redistributed in the central bar and at the same time outer bar EFU action will allow to deform again to the central bar. An initial residual stress doesn't contribute directly to EFU but they promote initiation of plasticity. Teramae, [5], proposed a new method named simplified method which can be used for analysis of Elastic follow-up.In this global and local reference stresses are newly defined and it is found that this method is much better than finite element analysis and flexibility factor method. It requires very less computing time. In this new proposed methodology actual creep properties are used for analysis purpose and structural analysis other than elastic analysis can be omitted [6].



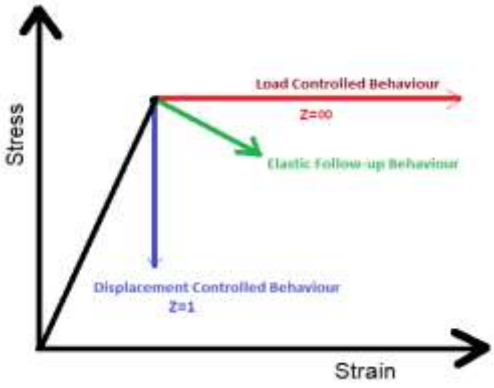


Fig.1: Stress strain relationship with EFU **Fig.2: EFU under Boundary condition [7]**

Elastic follow-up is strongly related to creep, which develops in various pipes due to application under high temperature operation for a long time. For example in a superheater, tubes wear when exposed to high temperature and high pressure for a long time. Axisymmetric pipes are subjected to combined primary and secondary stresses with varying magnitude. Secondary stress EFU is affected by the magnitude of the primary stress and primary stress increases elastic follow-up factors [8]. It will help in the design consideration on how EFU is affected due to primary and secondary stresses of any process plant.

It is essential that the system be loaded elastically (plasticity or creep) for any elastic follow-up to occur. If EFU occurs in structure, the elasticity of slightly stressed regions may act as a spring that loads the highly stressed regions [9]. This happens either at low temperature (time-independent phenomenon) or at high temperature (time-dependent phenomenon). In low temperature piping system thermal expansion stress is treated as secondary, but it requires evaluation of local overstrain in that structure.

II. PRESSURE VESSEL

Pressure vessel is very important for any industrial application. It is used in Power plant for boiler drum, deaerator, storage tank, reverse osmosis etc. and in various other applications like industrial autoclave, autoclave for medical field, compressor, gas cylinder, auto stove, petromax, fire safety instrument etc. Pressure vessels are leak proof containers. They may be ofvarious shapes and sizes like cylindrical, spherical, ellipsoids and these are subjected to pressure, temperature, seismic loads etc. Pressure vessel may be subjected to low pressure low temperature or high pressure high temperature according to its application. Depending upon these aspects, pressure vessel can be categorized in two: a) Thick pressure vessel b) Thin pressure vessel; and to standardize these vessel ASME and pressure vessel code have been defined to work in effective manner [10]

III. EQUIVALENT REDUCED ELASTIC MODULUS PROCEDURES

Modulus of elasticity is a measure of stiffness and modulus of elasticity decreases with rise in temperature. We can say that material has high stiffness if deformation in elastic range is relatively small. This property of stiffness is very important in design where deformation must be kept small [7]. Here equivalent reduced elastic modulus procedure has been used in assessment of Elastic follow-up in inelastic structure. This procedure is mainly used for piping system. It requires less time and low computational costs. Elastic stress is generated in most high stressed structural discontinuity region and corresponding strain will also have to be considered [11]. The simplified procedure to get a percentage of EFU used by Dhalla [2] is based upon the concept that inelastic response of an elbow, being part of a piping system and loaded by a thermal expansion stress, can be simulated by judiciously lowering its elastic modulus.

The elastic stress $\sigma_1$is generated in the most highly stressed structural discontinuity.In the Fig 3, heating of pressure vessel is represented by A. Corresponding to this value strain $\varepsilon_1$will be present. If this structural discontinuity experiences 100% Elastic follow-up, then elastic stress (σ_1) will be constant for various elastic modulus (E_1,E_2) values. For the same, calculated strain will increase from ε_1 to ε_2.

$$\sigma_1 = \sigma_2 \frac{\varepsilon_1}{\varepsilon_2} = \frac{E_1}{E_2}$$

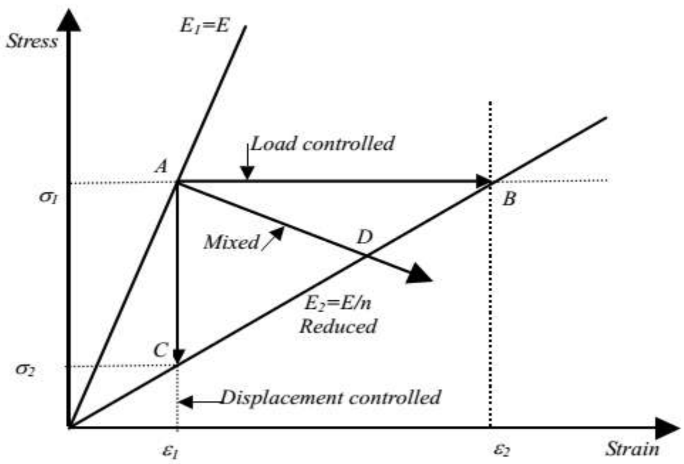


Fig. 3: Idealized load controlled and deformation controlled response [9]

If discontinuity is deformation controlled (0% EFU),the strain will not be changed due to reduced elastic modulus nevertheless stress decreases.

$$\varepsilon_1 = \varepsilon_2 \frac{\sigma_1}{\sigma_2} = \frac{E_1}{E_2}$$

Between both load controlled and deformation controlled, a mixed region is present which is influenced as Elastic follow-up.

Percentage of EFU can be estimated by $\frac{E_1/E_2 - \sigma_1/\sigma_2}{E_1/E_2}$

E_1 =Elastic Modulus
E_2 = Reduced elastic Modulus
σ_1 = Stress level for Uniform elasticity
σ_2 = Stress level for non-uniformity

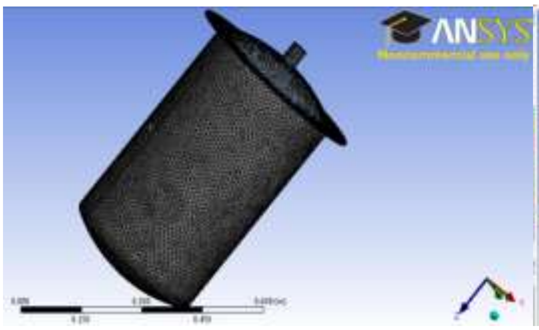
IV. AUTOCLAVE PRESSURE VESSEL ANALYSIS

Bacteria can be destroyed by using super-heated steam in an autoclave. Its primary objective is to sterilize materials and pieces of equipment before being used in laboratories or other facilities. Sterilization process means a complete destruction of all forms of microbial life, including bacterial spores through physical or chemical methods. In steam sterilization, microorganisms are killed thorough saturated steam under pressure. Pressure gauges and thermometers are used to regulate desired pressure and temperature. The manufacturing of high-performance components from advanced composites often requires autoclave processing. Autoclave pressure vessel is generally constructed using mild steel and its inner surface is stainless steel coated. This coating will secure the autoclave from wear due to extreme condition. So here it is assumed that autoclave vessel is completely made of mild steel ASME SA516 Grade 70. As per 2004 with 2005 Addenda, ASME SA-516 is specification for pressure vessel plates, carbon steel, for moderate and lower-temperature service.

Total height = 540mm**Mechanical Properties**
Inner radius = 175mmDensity= 7833.41 kg/m^3
Outer Radius = 178.5mmPoisson's Ratio = 0.3
Uniform thickness = 3.5mmTensile Strength = 485-620 MPa
Lid height from Centre end = 45mm

TABLE I. ELASTIC PROPERTY FOR ASME SA-516 GRADE 70

No.	Temperature °C	Pressure (MPa)	Young's Modulus (GPa)	Thermal Expansion (/°C)	Thermal Conductivity W/m-K
1	37.7	0.0015	202.01	11.7×10^{-6}	46.1
2	65.5	0.0029	200.64	11.88×10^{-6}	45.3
3	93.33	0.0034	198.57	12.06×10^{-6}	44.7
4	104	0.015	198.56	12.09×10^{-6}	43.8
5	108	0.0345	198.89	12.14×10^{-6}	43.5
6	115	0.103	197.01	12.24×10^{-6}	42.9
7	121.1	0.0689	197.19	12.24×10^{-6}	43.8
8	130	0.138	195.01	12.36×10^{-6}	42.7



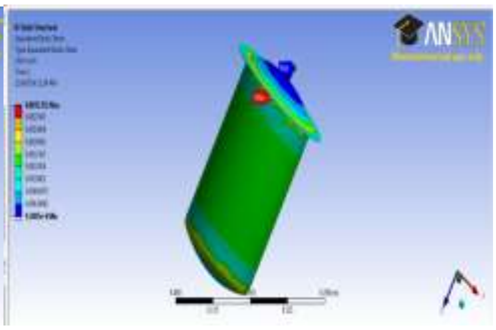
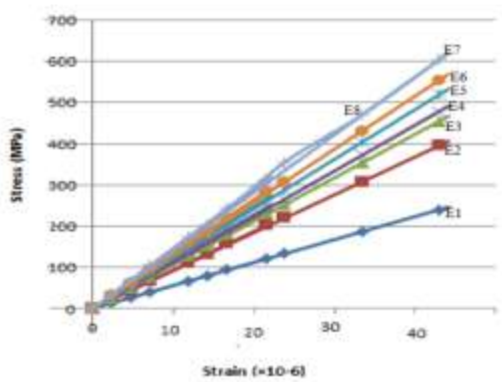


Fig.4: Meshed Autoclave Pressure vessel

Fig.5: Von-Mises Strain for maximum temperature



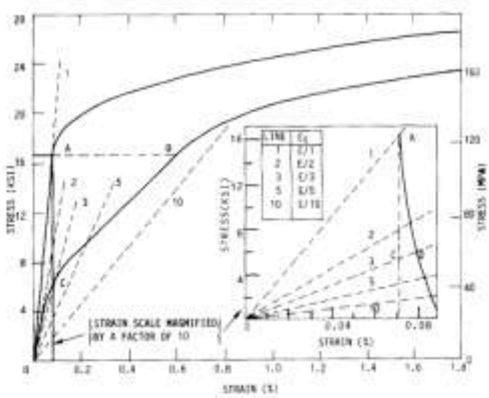


Fig.6: Isochronous stress strain curve for different moduli

Fig.7: Isochronous stress strain curve for different moduli [9]

TABLE II. RESULT FOUND OUT BY ANALYSIS

Elastic Moduli	E1	E2	E3	E4	E5	E6	E7	E8
Temperature °C	37.7	65.5	93.33	104	108	115	121.1	130
Pressure (MPa)	0.0015	0.0029	0.0034	0.015	0.0345	0.103	0.0689	0.138
% EFU	0	64.45	78.64	81.47	82.83	83.82	84.86	86.26

V.CONCLUSION

The influence of pressure and temperature on the mechanical behavior of the autoclave has been observed. Also the percentage of Elastic follow-up for this autoclave analysis has been found out. The maximum stress which is found to be at the structural discontinuity of the autoclave is well within the material yield strength. Maximum deformations will occur resulting from numerical simulations at increasing temperatures and pressures. Stress value increases highly with an increase in temperature. It is also observed that when the pressure is increased stress value will also increase at upper top discontinuity region as a result. If this stress value exceeds more than 250 MPa (which is the yield stress of the corresponding material) then possibility of collapse in the operation may occur.

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