**STRESS DISTRIBUTION OF PVC/ POLYSTYRENE MATERIAL TUBE HAVING INTERNAL PRESSURE AND THERMO- MECHANICAL LOAD**

1Kanav Gupta , 2Neeru Gupta

 Department of Physics, Department of Mathematics

ICFAI University Himachal Pradesh ICFAI University Himachal Pradesh

India India

kanav17aug@gmail.com neeruguptagupta087@gmail.com

**ABSTRACT**

This article deals with the study of thermal stress distribution in a tube made of polyvinyl chloride/ polystyrene material and subjected to internal pressure and mechanical load. Through the acquired outcomes , it is remarked that value of pressure increases with increasing temperature  =0.0175 and decreases with increasing mechanical loads (i.e. L0 = 0.1 and 0.2) at the inner surface of polyvinyl chloride material tube and also in a polystyrene material tube for the initial /fully –plastic stage . The values of the circumferential / radial stress also increase with increasing temperature /mechanical loads in the compression/tension region of the tube. The polyvinyl chloride material tube is more convenient than that of polystyrene material tube.

**Keywords –** tube ; load ; stresses ; pressure ; temperature

1. **INTRODUCTION**

The analysis of Elasto-plastic thick-walled tubes have enticed a lot of concern due to their essential applications in chemical industry engineering, petrochemical industry, agricultural irrigation, urban construction, and electric power industry. For structural use in bridges, piling pipe, piers, roads, building structures, etc. and also body transport in gas, steam, liquefied petroleum gas, etc. The analytical solutions of stress distribution are given for idealized elasto-plastic by Timoshenko [2] and work hardening by Chadwick [3] for homogeneous materials. Bland [1] has analyzed the problem of thick- walled tubes with the addition of heated gradient and consistent pressure.Gamer et al. [4] achieved the analytical solution of stresses in thick walled tube through employing Tresca’s yield condition. Bree [5] has discussed the deformation of elasto - plastic stresses in a closed tube scheduled for thermal stresses. Mufit et al. [6] proposed heat generating tube with yield stress showing thermal stress distribution through employing Tresca's yield condition and its corresponding flow rule. Xin *et al.* [7] studied the elasto-plastic behavior of functionally graded thick-walled tube with the addition to internal pressure by applying the supposition of a invariable strain field within the volume element and the Tresca yield criterion. Matvienko et al. [10] analysed the aluminum tube elastoplastic deformation of under inner/ outer pressure. Futher Matvienko et al. [11] examined mathematical modeling in dispersion-hardened aluminum alloy tube with non- homogeneous thermal field.[Qian](https://www.ncbi.nlm.nih.gov/pubmed/?term=Qian%20C%5BAuthor%5D&cauthor=true&cauthor_uid=31947636) et al. [9] developed mechanical properties of extremely well organized heat interchange tubes. Gupta et al. [8] has investigated the deformation of stress in a thick walled tube made of isotropic material with the inclusion of inner pressure and thermo mechanical load through employing transition theory.It has been seen that, with the introduction of mechanical loads the value of pressure decreases. The objective of this article is to be investigating stress distribution in a thermo mechanical loaded tube made of PVC/ polystyrene material and subjected to uniform pressure.

1. **MATERIALS USED**

**A. Polyvinyl Chloride (PVC):** It is a prudent   [and adaptable thermoplastic polymer](https://omnexus.specialchem.com/selectors/c-thermoplastics-pvc-polyvinylchloride?src=sg-overview-cnx" \t "_blank). To construct the building of industries , schools , universities , govt buildings ,hospitals , factories , gas storage tanks ,marines etc. (*i.e*  to produce wire and cable insulation , door and window profiles, pipes (drinking and wastewater), medical devices, etc. ) . It is a good dimensional stability at room temperature and low cost , [flexible](https://omnexus.specialchem.com/polymer-properties/properties/flexibility?src=sg-overview-cnx) and high impact strength , good electrical insulation and vapor barrier properties etc.

**B. Polystyrene:** It is a monomer styrene polymer (*i.e* liquid hydrocarbon obtained from petroleum). It is solid plastic products that require clarity (*i.e.* laboratory ware). After the combination of different colorants, additives /various plastics, it is useful to instruct gardening pots, research labs material / appliances/ equipments, automobile parts, toys, electronics etc. It provides superior insulation, water resistant, resistant to bacterial growth, excellent shock absorbers.

1. **MATEMATICAL MODEL**
2. **Abbreviations and Acronyms**

 - lame’s constants,  *- first strain invariant, C- compressibility factor,**,* 

 *- inner and outer radii, u,v,w- displacement components*

 *- poisson’s ratio,*  *- components of stress and strain*

* - yielding stress,* 

 *- kronecker’s delta pi. - inner surface of pressure ,*

*Pi - initial yielding stage pressure Pf - fully-plastic stage pressure ,*

*- load at the outer surface,*  *- function of r ,*  *- function of x and y*

* - function of , Θ - temperature ,*  *- constant of integration*

1. **Non-dimensional quantities:**

** **-*Radii ratio*, ****-*Radial stress component*, **** -*Circumferential stress component*,****-*Mechanical load***, ** -*Temperature****,* *and* ** - *Pressure.*

**C. Equations**

The tube is taken in the form of cylinder made of Polystyrene and Polyvinyl chloride material, with an inner radius *ri* and external radius *r0* (*ri* < *r0*), with the inclusion of invariable pressure *pi* respectively. Let us consider uniform temperature be applied at the inner surface of the tube. Further, if we suppose that there are body couples, no body forces and couple stresses on the tube, and if only a steady deformation problem is considered as shown in Figure 1.



**Figure. 1** Polystyrene/ Poly vinyl chloride materials tube.

*Basic Governing Equation*: The cylindrical polar coordinatesare shown [12-16, 8]:

 (1)

The strain components of Almansi are shown [16,17]:

 ,  ,

 ,  (2)

 Isotropic material relations are shown [12,14]:

,  (3)

Using (2) into (3),we get

 

 (4)

The equilibrium equation is shown as:

  (5)

Using the equation andat, at . After applying these conditions we obtained the new relation :

  (6)

where

*Boundary condition:* The boundary conditions of the tube ( *say* compression /tension region) are:

at *r* = andat *r* = (7)

Using (4) into (5) then we obtained the differential equation:

 (8)

where *A*0 is the constant of integration*.* Differentiating (8) w .r. t to *r*, given as under :

**  (9)

*Problem solutions:*

*(a) Case of compression* :The transition function as:

  (10)

By applying differentiation , integrating in (10) and using (9) as well, we obtained the function :

  (11)

Comparing, (10) and (11), we obtain the radial stress:

 (12)

The yielding stress in compression is given [8-17]. Now substituting the value of yielding stress condition in (12), we get

  (13)

By applying (7) into (13), necessary relation obtained Further, (13) become:

  (14)

 Now by applying (7) into (14), necessary relation obtained

 (15)

Substituting (15) into (14) and using (7) :

 (16)

 (17)

From (16) and (17), we get:

 (18)

*Initial yielding stage:* Taking (18), and using *r* = *ri*, therefore yielding becomes: (say);

 (19)

 (16), (17) and (19), in non-dimensional form becomes:

 

 (20)

***Fully-plastic stage:* (20) obtained :**

,,

 (21)

*(b)**Case of tension :*The transition function as:

 (22)

 By applying differentiation, integrating in (22) and using (9) as well, we obtained the function:

 (23)

Comparing, (22) and (23), we obtain the radial stress

 (24)

The yielding stress in tension is given [8-17]: Now substituting the value of yielding stress condition in (24), we get

  (25)

Now By applying (7) into (25), necessary relation obtained Further, (25) become:

 (26)

Now By applying (7) into (26), necessary relation obtained

 (27)

Substituting (27) into (26) and using (7) :

 (28)



 (29)

From (28) and (29), we get:

 (30)

*Initial yielding stage:* Taking (30), and using *r* = , therefore yielding becomes: 

 (31),

(28)-(29) and (31), in non-dimensional form becomes:

 



and 

 (32)

*Fully-plastic stage:*  **(32) obtained :**

,

,

  (33)

**IV VALIDATION OF RESULTS**

By applying Θ1 →0 into (20), (32), and (21) , (33) we get the Initial Yielding/ Fully plastic stage*:*

 

 (34)

in the case of compression region .





 (35)

in the case of tension region .

 

,

 (36)

in the compression /tension region. The present results obtained from (34) - (36) are same as given by Gupta et al. [8] in the tension/compression region.

**A.Figures**

To see the combined effect of stress distribution and pressure in a cylindrical tube made of Polyvinyl chloride , PVC (say *C* = 0.3333 or *v* = 0.4) and Polystyrene, PS (say *C* = 0.46154 or *v* = 0.35) [17]: *L*0 = 0, 0.1, 0.2; Θ1  = 0, 0.0175, 0.07; *ri* = 1 and *r0* = 2 respectively.

**(a)**

**(b)**

**Figure. 2** Dimensionless pressure versus *R*0 in the (a) compression (b) tension region

In Figure.2, the graph is plotted between radii ratio *R*0 versus dimensionless pressure for the compression / tension region with *.* *L*0= 0, 0.1, 0.2 and  = 0, 0.0175 resp. It has been seen that in the initial yielding stage polyvinyl chloride material tube requires maximum pressure to yield at the inner surface as compared to the polystyrene material tube . With increasing  =0.0175 /  *L*0= 0.1 and 0.2 the value of pressure increases / decreases respectively .

Figure. 3 graph has been drawn between stress distribution versus radii ratio *R* with *L*0= 0, 0.1, 0.2 and  = 0, 0.0175 respectively. Firstly, noticed that at the outer surface PVC tube desires greatest circumferential stress in collation to polystyrene material tube. Wth increasing  = 0.175/ *L*0= 0.1, 0.2 the hoop / radial stress values also increases .

**(a)**

**(b)**

**Figure. 3.** Stress distribution versus *R* in the (a) compression (b) tension region

**Figure. 4.** Pressure versus mechanical load at R0 = 0.5

Figure. 4 graph has been drawn between pressure versus mechanical load and having temperature  = 0, 0.0175, at *R*0 = 0.5. With increasing *L*0 = 0.1, 0.2 and  = 0.175 the value of pressure decrease and increases respectively. Further with increasing *L*0  , the PVC material tube wishes greatest pressure in collation to polystyrene material tube.

Figure. 5 is plotted between pressure versus temperature with *L*0 = 0, 0.1, 0.2 at *R*0 = 0.5. In the compression region, the value of pressure increases with increasing temperature (*i.e.*  = 0, 0.0175, 0.07), but in the case of tension region, the value of pressure neither increases nor decreasing. Furthermore, the values of pressure decreases with the mechanical load *L*0 = 0.1, 0.2 the tube made of polyvinyl chloride/ polystyrene material .

**Figure. 5.** Pressure versus temperature at R0 = 0.5

**CONCLUSIONS**

The main conclusions are shown as under :

* For the initial yielding stage, the PVC material tube requires maximum dimensionless pressure to yield at the inner surface in comparison to the polystyrene material tube.
* With increasing mechanical loads, the tube made polyvinyl chloride material requires maximum pressure in contrast to polystyrene material tube.
* The values pressure decreases with the mechanical load L0 = 0.1, 0.2 in compression / tension region of PVC/ polystyrene material tube.
* The PVC tube requires higher circumferential stress at the outer surface as compared to polystyrene material tube.
* With increasing  = 0.175 and *L*0= 0.1, 0.2, the circumferential / radial stress also increases in the compression /tension region of the tube.
* In tension region, tube requisite higher circumferential stress situated at the outer surface of the initial yielding stage as compared to compression region and inverse results are obtained with the involvement of temperature conditions.
* Gupta et al. [8] results can be obtained by taking →0 in the resulting equations.

**REFERENCES**

1. D. R. Bland, “Elastoplastic thick-walled tubes of work-hardening material subject to internal and external pressure and to temperature gradients,” J. Mech. Phys. Solids, vol. 4, 1956 , pp. 209-229
2. S. Timoshenko, and J.N. Goodier, “ Theory of elasticity” (McGraw-Hill Book Company, New York, 1970.
3. P. Chadwick, “Compression of a spherical shell of work-hardening material,” Int. J. Mech. Sci., vol. 5, 1963, pp.165–182.
4. U.Gamer, W.Austria ,and R.H. Lance, “Stress distribution in a rotating elastic- plastic tube ,”Acta Mechanica , vol. 50 ,1983 pp.1-8
5. J. Bree , “Plastic deformation of a closed tube due to interaction of pressure stresses and cyclic thermal stresses,” [Int. J. of Mech. Sci.](https://www.sciencedirect.com/science/journal/00207403), vol.[31,](https://www.sciencedirect.com/science/journal/00207403/31/11%22%20%5Co%20%22Go%20to%20table%20of%20contents%20for%20this%20volume/issue) 1989, pp.865-892
6. G. [Mufit,](https://www.sciencedirect.com/science/article/abs/pii/S0020722599000142%22%20%5Cl%20%22%21) and O. [Yusuf](https://www.sciencedirect.com/science/article/abs/pii/S0020722599000142%22%20%5Cl%20%22%21), “Elastic-plastic deformation of a heat generating tube with temperature dependent yield stress," Int. J. Eng.Sci., vol.38, 2000 pp. 89-106.
7. L. Xin, G. Dui, S.Y. Yang, and Y. Liu, “Elastic-plastic analysis for functionally graded thick-walled tube subjected to internal pressure”, Advances in Applied Mathematics and Mechanics Adv. Appl. Math. Mech., vol.8, 2016, pp. 331-352
8. K. Gupta, , P. Thakur , and R.K. Bhardwaj, “Elasto-plastic stress analysis in a tube made of isotropic material and subjected to pressure and mechanical load”, Mech of Solids, vol.57 , 2022
9. C. [Qian](https://www.ncbi.nlm.nih.gov/pubmed/?term=Qian%20C%5BAuthor%5D&cauthor=true&cauthor_uid=31947636),  [Z. Wu](https://www.ncbi.nlm.nih.gov/pubmed/?term=Wu%20Z%5BAuthor%5D&cauthor=true&cauthor_uid=31947636) ,  [S. Wen](https://www.ncbi.nlm.nih.gov/pubmed/?term=Wen%20S%5BAuthor%5D&cauthor=true&cauthor_uid=31947636) , S. [Gao](https://www.ncbi.nlm.nih.gov/pubmed/?term=Gao%20S%5BAuthor%5D&cauthor=true&cauthor_uid=31947636) , and G.   [Qin](https://www.ncbi.nlm.nih.gov/pubmed/?term=Qin%20G%5BAuthor%5D&cauthor=true&cauthor_uid=31947636) , “Study of the mechanical properties of highly efficient heat exchange tubes, [Materials (Basel),](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7013435/)  vol.13, 2020 pp. 382
10. O.V. Matvienko, O.I. Daneyko, and T.A. Kovalevskaya, “Elastoplastic deformation of dispersion-hardened aluminum tube under external pressure,” Russ. Phys. J., vol. 61,2018 pp.1520–1528
11. O.V. Matvienko, O.I. Daneyko, and T.A. Kovalevskaya, “Elastoplastic deformation of dispersion-hardened aluminum tube under external and internal pressure,” Russ. Phys. J. , vol.62,2019 pp.720–728
12. B.R. Seth, “Transition Theory of Elastic - Plastic Deformation, Creep and Relaxation,” Nature, vol.195, 1962 ,pp.896-897 .
13. I.S. Sokolnikoff , “ Mathematical theory of elasticity”, 2nd ed. (McGraw - Hill Book Company, New York, 1956).
14. B.R. Seth, “Elastic-plastic transition in shells and tubes under pressure,” ZAMM, vol.43,1963 pp.345-351.
15. B.R. Seth, “Transition condition, the yield condition,” Int. J. Non-Liner Mech, vol.5, 1970, pp.279-285.
16. P. Thakur , M. Sethi, N. Gupta, and K. Gupta, “Thermal effects in rectangular plate made of rubber, copper and glass materials,” J Rubber Res, vol.24, 2021, pp.147–155.
17. <https://polymerdatabase.com/polymer%20physics/Poisson%20Table.html>.