

Creep analysis of Water tank made of Polypropylene (PP) and High-Density Polyethylene (HDPE) polymer material using ANSYS Simulation

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ABSTRACT

The present study investigates the creep behavior of water tank manufactured from Polypropylene (PP) and High-Density Polyethylene (HDPE) polymeric material at 40 °C using ANSYS simulation software. Creep fracture is one of the major industrial problems for a product used for a long period of time. The creep analysis using simulation software is one of the ways to predict the life and durability of a plastic product with low cost and may help in optimizing its design. The PP and HDPE manufactured water tanks were commonly used for storing water in household and industrial applications. In this paper, a water tank were designed using an academic 3-Dimensional SOLIDWORKS software and ANSYS WORKBENCH were used for analyzing the creep strain for the developed CAD model. The CAD modelled water tank was tetrahedron meshed and simulated using static structural analysis and varying hydrostatic pressure were applied on the inner walls of the tank. The base of the tank was constrained to fixed. The analytical model based on modified time hardening creep model were implemented to analyze the creep strain. From the simulation, equivalent (Von-Misses) Stress, equivalent creep strain and total deformation were observed for the developed model. The obtained Creep strain-time graph were used to analyze the creep strain of PP and HDPE materials over a long period of time. From the simulation, it is observed that the material PP is more creep resistant than HDPE as equivalent stress of PP is more than HDPE at the applied hydrostatic pressure and the deformation for PP material were less compared to HDPE. The simulated limiting creep strain of PP as well as HDPE

was in good agreement with the comparison of maximum limiting creep strain calculated from the material database.

Keywords: Creep; Stress; Strain; Ansys; Water tank; Solid works.

INTRODUCTION

Rotational molding is one of the polymer processing techniques used for making hollow products ranging from small water tank to big fuel tanks (Crawford et al., 2003). The life expectancy of the rotational molding products is from few to several decades and the study of mechanical properties of polymer materials are of importance as it can provide valuable data of the product life cycle. Due to viscoelastic nature of polymer, the time and temperature play a foremost role in the mechanical behavior of polymers (Adibeig et al., 2019). In terms of designer point of view for products to have long period of lifetime, the creep behavior is one of the important mechanical properties for designers to study as it is the time dependent deformation of material. Creep rupture which is the crack formation which acts as a function of time when the product subjected to continuous stress. Therefore, the conventional experimentation method may not be feasible to study for long term creep behavior due to limited time for product development and hence simulation of creep analysis of the product is needed to determine the creep behavior after a long period of time are required to know the product conditions (Pozhil et al., 2020).

Many analytical models are used by different researchers to predict the creep behavior of polymeric materials (Acha et al., 2007; Almagableh et al., 2015; YaylaçI et al., 2019 (a); YaylaçI et al., 2020; Malika et al., 2021; Zhang et al., 2021 & Faizan et al., 2021). Dropik et al., 2002 investigated the modelling of primary creep of polypropylene. The gathered experimental data were used to calculate the creep constant using non-linear Maxwell model by using ANSYS software. They compared the creep strain experimentally and the ANSYS simulated model. The error was found to be 11.1% which represent 0.016-inch error after one hour in 4-inch specimen. Further, Dean et. al., 2007 studied the creep behavior of

polypropylene under uniaxial tension on a rectangular bar specimen of 160mm. They modelled a non-linear creep from linear viscoelastic model using spring and viscous dashpot elements in series and parallel. Nitta et. al., 2010, studied the creep behavior of HDPE when subjected to true stress. A dumbbell shaped specimen of 10mm width and 40mm gage length were used to study the creep behavior over different temperatures. The creep compliance on stress were depended positively showing the nonlinear viscoelastic behavior. Farid et. al., 2017 studied the long-term creep properties in HDPE pipes. Uniaxial creep test samples were made using HDPE bars and was carried out at different temperatures under a constant stress. A creep constitutive equation was used to find the relation of creep strain rate with stress and temperature. Pozhil et. al., 2019 modelled time hardening model to study the creep behavior of LLDPE and PP at 40 °C. They used Maxwell creep equation to find the creep constants from the experimental data. After simulating the creep test in ANSYS they compared the long-term creep behavior of PP and LLDPE. They found that PP have higher creep resistance than LLDPE and can be used in areas having higher working temperature. YaylaçI et al., 2019 (b) studied the elastic layer contact problem on the rigid foundation using ANSYS software. They found various dimensionless parameters for the contact length between the punch and the layer. Beradi et al., 2021 studied the creep experiments and analytical on uniaxial E-glass fiber reinforced polymer composites at various stress levels. They found that the deferred creep behavior for the composites is used for repairing the hydrogen transportation pipes. Kyzy et al., 2021 investigated the creep behavior of PP with short glass fibers at various temperatures. They suggested that the creep results may be used to estimate the lifetime of products.

The study of the creep characteristics for the product during the stage of development using long term creep testing may not be feasible due to long period of time were required for the testing. Therefore, the novelty of the present work lies in the simulation of the product water tank using ANSYS software's to study the creep behavior of the product with the advantage of low cost and time. To the best of our knowledge, studying the creep behavior of PP and

HDPE polymer materials at 40 °C for water tank using modified time hardening model have not yet been investigated. A modified time hardening model is one of the basic models commonly used to analyze the creep effect of polymers. The product water tank has been selected for the creep analysis as it is widely used all over the world to store water for a long period of time for almost 30 years of life. The polypropylene (PP) and high-density polyethylene (HDPE) polymer materials are selected for the study as it is widely used materials to manufacture water tanks and other mechanical structures. The objective of the present work is to study the creep behavior of water tank using ANSYS workbench for PP and HDPE material at 40 °C which are subjected to constant stress and required to be designed for a long time period.

EXPERIMENTAL DETAILS

MATERIALS

In the present study, Polypropylene (PP) and High-density polyethylene (HDPE) polymer materials are selected from the library of ANSYS, and their properties are also imported from the library for the product water tank. The mechanical properties of the PP and HDPE materials are shown in Table 1.

Table 1. Mechanical Properties of PP and HDPE

Specifications	PP	HDPE
Density (kg/mm ³)	9.02e-07	9.58e-07
Young's Modulus (MPa)	915	1080
Poisson's Ratio	0.443	0.418
Tensile Ultimate Strength (MPa)	29.9	29.6
Tensile Yield Strength (MPa)	26.2	25.7

CAD MODELLING AND MESHING

The 3D CAD model of water tank was designed by using SOLDIWORKS software. The

water tank was modelled for a capacity of 1000 litres and the dimension of the tank are Height of the tank = 940mm; Radius of the tank = 600mm; Manhole diameter = 400mm; Thickness of the tank = 5mm and are shown in Figure 1. Then, the developed CAD model are imported into ANSYS workbench. Before analysis, the modelled water tank was meshed using program-controlled linear tetrahedron meshing which resulted in 52154 nodes and 26034 elements on Ansys meshing tool and meshing is one of the most important steps in the simulation process. The meshed water tank and statistics of nodes and elements used for the simulation are shown in Figure 2.

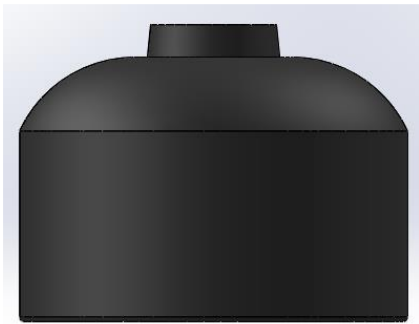


Figure 1. CAD Model of Water Tank

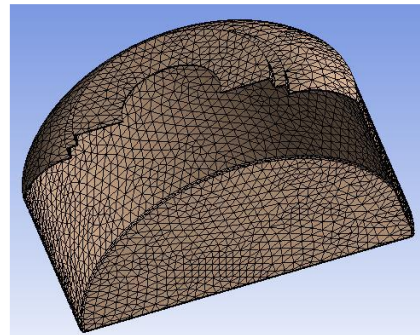


Figure 2. Meshed Water tank

BOUNDARY CONDITIONS AND SIMULATION

The base of the water tank was fixed, and the hydrostatic pressure were applied on the inner wall of the tank. The water tank was simulated using static structural analysis model and is shown in Figure 3. The modified time hardening creep model are selected as an analysis model for the simulation to predict creep strain. The creep behavior was studied for $1e+9$ seconds which is around 31 years of life and the creep control in the solver are kept on for the analysis and is shown in Figure 4.

The modified time hardening model that will be used for the creep analysis of water tank of PP and HDPE needs four creep constants as input. These creep constants define the creep property of a material and is given in Equation (1).

$$\epsilon_{cr} = (c_1 \sigma c_2 t c_3 + 1 e^{-c_4/T}) / (c_3 + 1) \quad \text{where } c_1 > 0 \quad (1)$$

Where c_1 , c_2 , c_3 , and c_4 are creep constants; ϵ_{cr} is equivalent creep strain; σ is Equivalent

stress; T is Absolute temperature and t is time. The modified time hardening equation creep constants are calculated using a mechanical APDL curve fitting method (Lombroni et al., 2021) by inserting the creep curve data generated from the existing literature for PP (Crawford et al., 2020) and HDPE (Pan et al., 2016). The creep constants calculated by solver by using curve fitting method for PP and HDPE material are shown in Figure 5 (a) and (b).

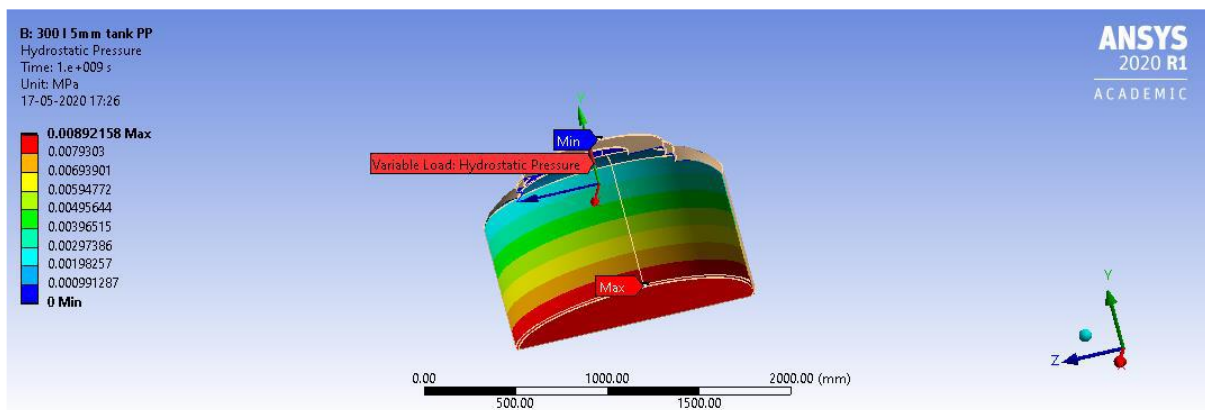


Figure 3. Boundary Conditions on the Water tank

Details of "Analysis Settings"	
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1.e+009 s
Auto Time Stepping	Program Controlled
Solver Controls	
Rotordynamics Controls	
Restart Controls	
Creep Controls	
Creep Effects	On
Creep Limit Ratio	1.
Nonlinear Controls	
Advanced	
Output Controls	
Analysis Data Management	
Visibility	

Figure 4. Analysis settings for the simulation

```
Iteration Number = 1000
Coeff 1 = 2.684372e-05
Coeff 2 = 1.317695e+00
Coeff 3 = -8.818409e-01
Coeff 4 = 2.345949e-11
```

```
Iteration Number = 1000
Coeff 1 = 2.815504e-05
Coeff 2 = 1.681657e+00
Coeff 3 = -8.243759e-01
Coeff 4 = 1.114320e-10
```

Figure 5. Creep constants from simulation for (a) PP (b) HDPE

RESULTS & DISCUSSIONS

ANSYS workbench software was used for the static structural simulation to predict the creep behavior for the product water tank made from PP and HDPE polymer material. The model was designed, and boundary conditions are applied on the model to make the product more efficient and simulating for Equivalent (Von-misses) stress, Equivalent creep strain, Total deformation, and Creep strain-time curve are selected for the study.

EQUIVALENT (VON-MISSES) STRESS

The static structural simulation was used to calculate the equivalent (Von-misses) stress with varying hydrostatic pressure was applied on the inner walls of the tank. The maximum equivalent stress generated are 3.15 MPa for PP and 2.63 for HDPE after a time period of $10e+9$ seconds and are shown in Figure 6 and 7. From the Figure it is evident that the maximum stress is generated at the base of the tank and the minimum stress is generated at the top of the tank where the hydrostatic pressure is zero. It is also seen from the analysis that the equivalent stress of PP is more than HDPE at the same applied hydrostatic pressure (Pozhil et al., 2020).

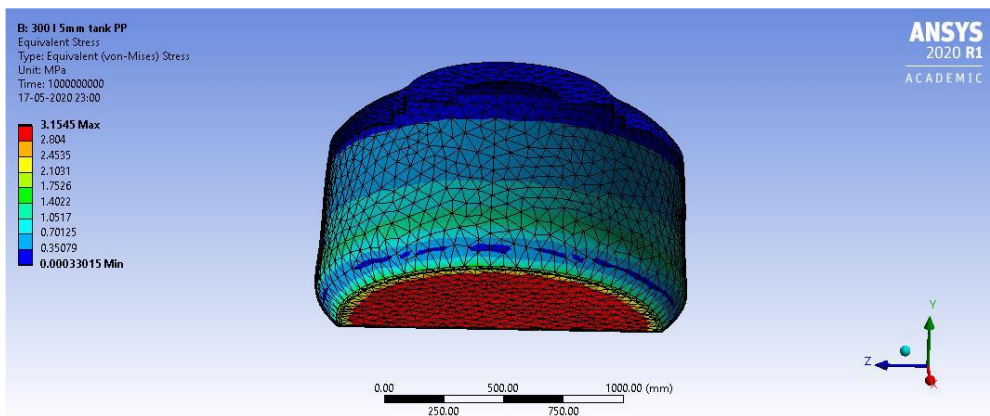


Figure 6. Equivalent (Von-misses) stress of PP

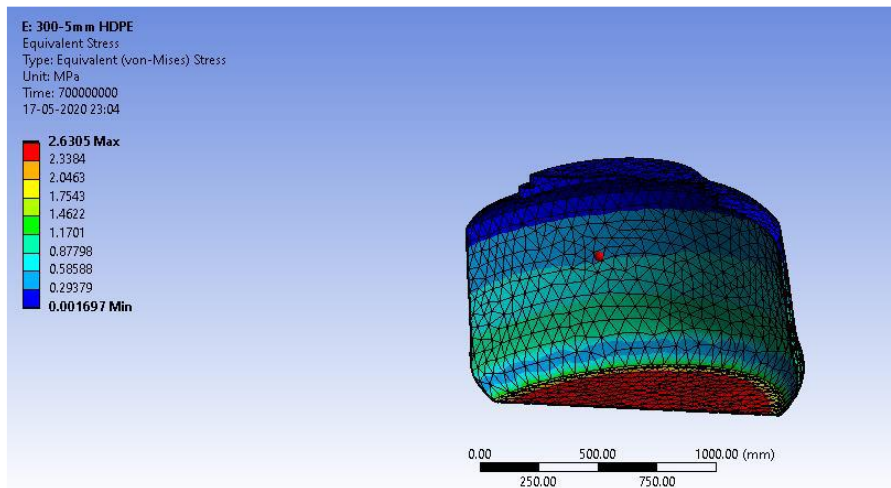


Figure 7. Equivalent (Von-misses) stress of HDPE

EQUIVALENT CREEP STRAIN

The creep behavior of both the material was studied for a time period of 31 years. As generally the water manufacturing companies gives a warranty for water tank up to 20 years. Hence, the water tanks should be designed to work for more than the period. The equivalent creep strain data for PP and HDPE are shown in Figure 8 and 9. The maximum equivalent creep strain for PP is 0.304% and for HDPE it is 0.522%. From the simulation it is found that the maximum creep strain for PP and HDPE were found at the bottom of the tank and the minimum at the top of the tank due to increase in hydrostatic pressure at the bottom of the tank (Farid et. al., 2017).

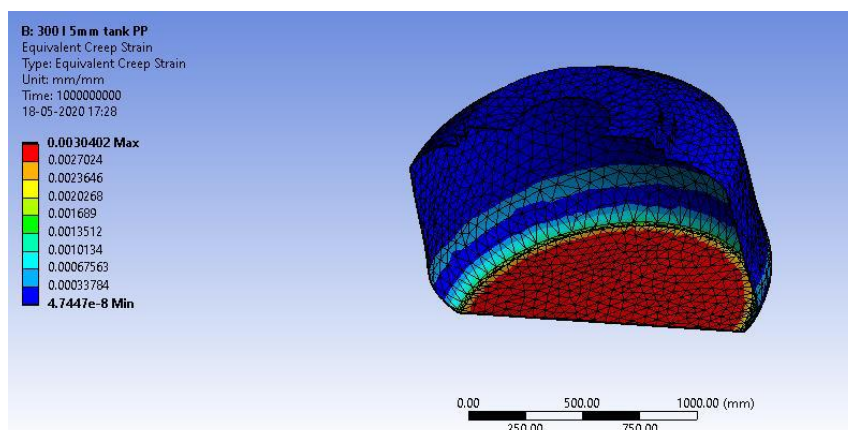


Figure 8. Creep strain distribution of PP

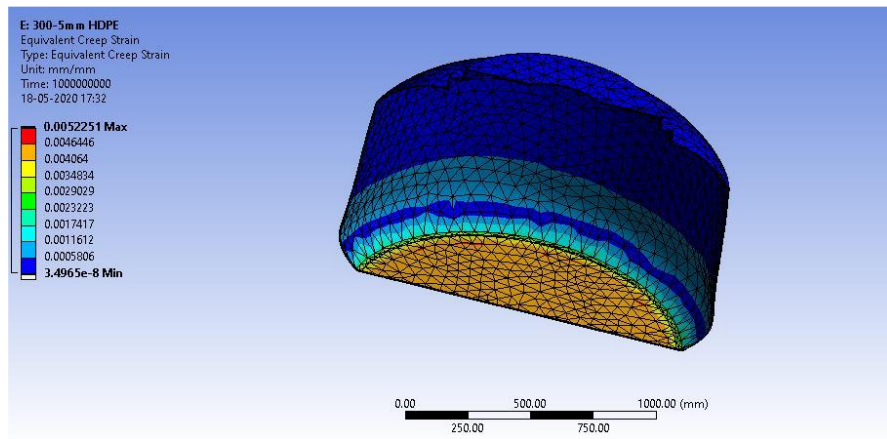


Figure 9. Creep strain distribution of HDPE

TOTAL DEFORMATION

The maximum deformation in the tank was also analyzed to design the tank. The PP water tank deformed about 2.898 mm and the HDPE tank deformed for about 3.902 mm which has been illustrated in Figure 10 and 11. From the maximum deformation figures, it is evident that the HDPE tank was deformed more than the PP tank with the same analysis settings. It is also found that the maximum deformation for both the materials on the bottom of the tank due to hydrostatic pressure applied.

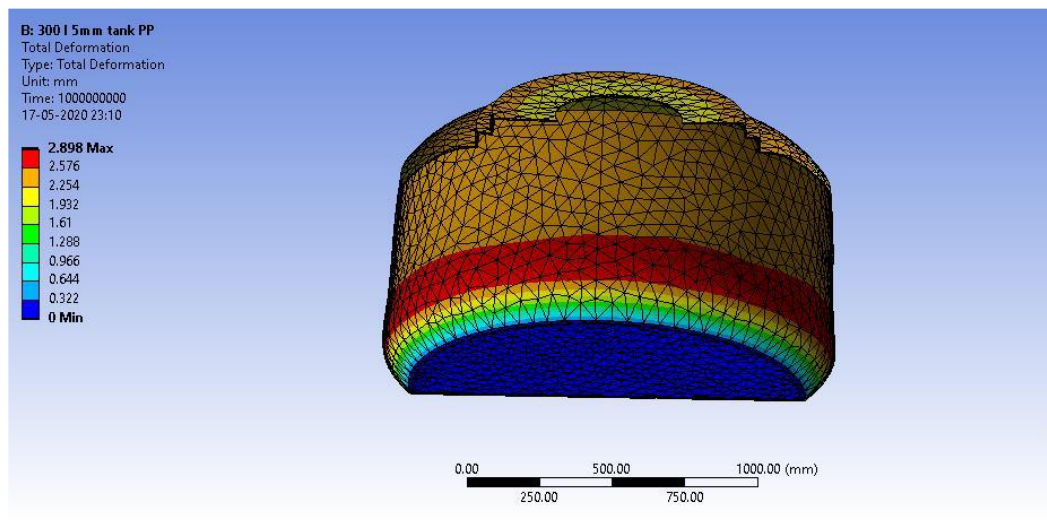


Figure 10. Maximum deformation of PP

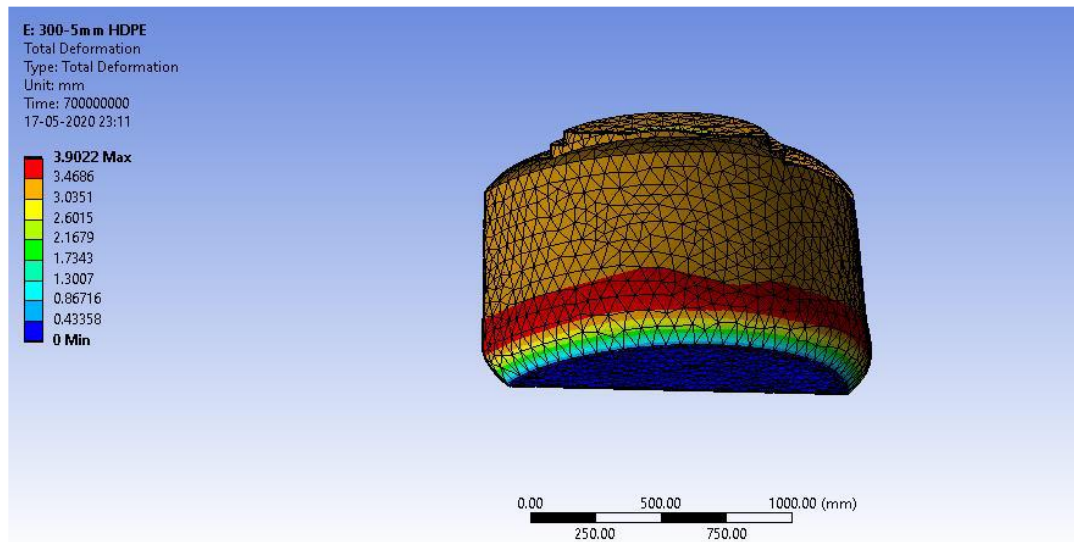


Figure 11. Maximum deformation of HDPE

CREEP STRAIN-TIME GRAPH

The creep strain % (mm/mm) vs time (sec) graph were plotted using the creep strain output from the ANSYS simulation. The logarithmic graph from the data were plotted for PP (Figure 12) and HDPE (Figure 13). The maximum creep strain was achieved for the time period of $10e+9$ seconds for both PP and HDPE materials. It is also found from the study that the creep strain is increased with time for PP and HDPE material respectively as expected from the study.

CREEP STRAIN LIMIT

Creep strain limit defines the material's resistance to creep. It is the maximum strain that can be endured by the material before it fails. The creep strain of both the material can be calculated with the help of material properties and factor of safety. Since water tank are designed to have long life and are exposed to harsh weather all over the world, so the factor of safety of the product was decided to be in between 4-5.

For PP:

$$\epsilon_y = \frac{\sigma_y}{E} \quad (2)$$

$$\epsilon_y = 26.2 / 915 \text{ (Value from Table. 1)}$$

$$\epsilon_y = 0.0286 \text{ or } \epsilon_y = 2.86\%$$

$$\epsilon_{\text{creep}} (\text{PP}) = 2.86 / 4.5 = 0.635\%$$

For HDPE:

$$\epsilon_y = 25.7 / 1080 \text{ (Value from Table. 1)}$$

$$\epsilon_y = 0.0237 \text{ or } \epsilon_y = 2.37\%$$

$$\epsilon_{\text{creep}} (\text{HDPE}) = 2.37 / 4.5 = 0.526\%$$

The creep strain for PP was calculated to be 0.635% and for HDPE it is 0.526%. From the simulation the limiting strain is 0.304% and 0.522% for PP and HDPE respectively. Hence, it is evident that the water tank can be designed from both the materials for the specified period of time and analysis settings as the simulated limiting strain is lesser than the calculated limiting strain.

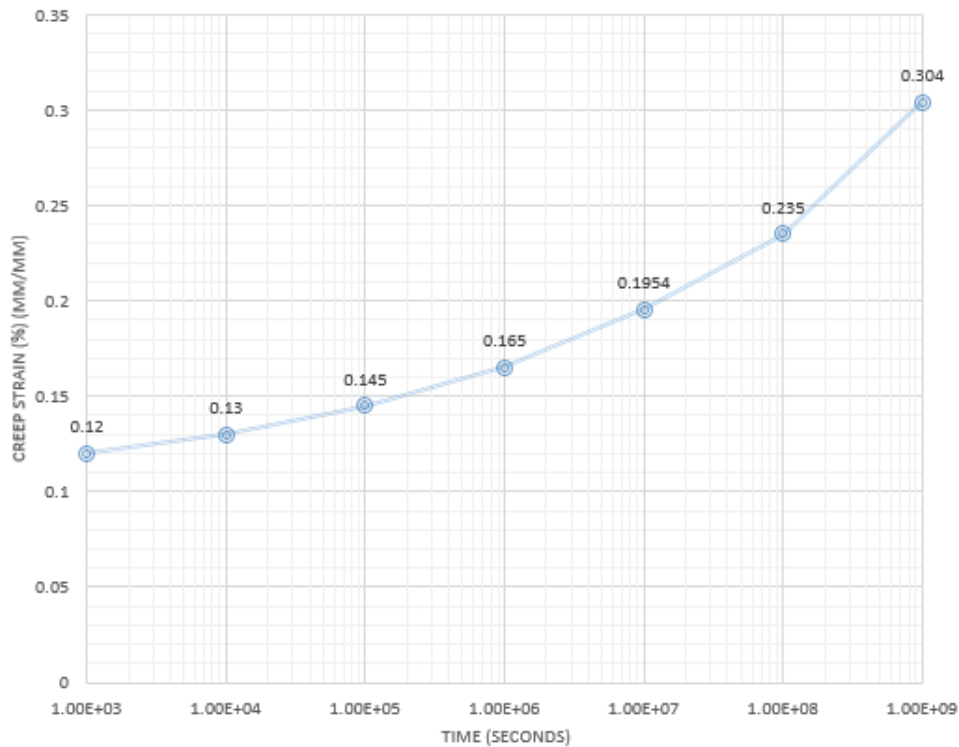


Figure 12. Creep curve of PP

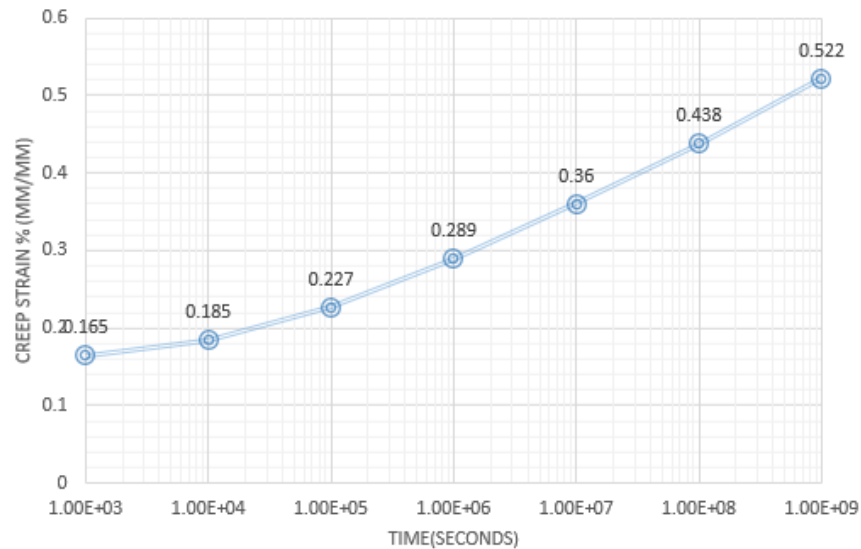


Figure 13. Creep curve of HDPE

CONCLUSION

The creep analysis of water tank made of PP and HDPE was done and the results were compared. The simulation model was done in static structural, and the hydrostatic pressure was applied on the inner wall. The creep constants for both the materials were derived from the creep curve from a research paper by solving it in ANSYS mechanical APDL. A modified time hardening creep model was used to analyze the creep behavior of PP and HDPE material for the product water tank. The outcome of the present study has been given in the following points:

- The material polypropylene (PP) is more creep resistant than HDPE when the same hydrostatic pressure and time period was applied on the tank of same size.
- The equivalent Von misses stress for PP was higher than HDPE and that might be because PP have better strength and impact resistance than HDPE.
- The maximum equivalent creep strain for PP is 0.304% and for HDPE it is 0.522%.
- The deformation for PP made water tank was also less than HDPE.

Finally, it is concluded from the simulation point of view that PP material may be suitable and as an alternative for HDPE for the manufacture of water tanks if long period of time

were considered for the design of the product.

REFERENCES

- Acha, B. A., Reboledo, M. M., & Marcovich, N. E. 2007.** Creep and dynamic mechanical behavior of PP–jute composites: Effect of the interfacial adhesion. *Composites Part A: Applied Science and Manufacturing*, 38(6), 1507-1516.
- Almagableh, A., Mantena, R., Alostaz, A., & Awad, A. S. 2015.** Analytical prediction of creep behavior in polymeric-based nanocomposites. *Journal of Reinforced Plastics and Composites*, 34(9), 687-695.
- Adibeig, M. R., Hassanifard, S., & Vakili-Tahami, F. 2019.** Optimum creep lifetime of Polymethyl Methacrylate (PMMA) tube using rheological creep constitutive models based on experimental data. *Polymer Testing*, 75, 107-116.
- Berardi, V. P., Perrella, M., Armentani, E., & Cricrì, G. 2021.** Experimental investigation and numerical modeling of creep response of glass fiber reinforced polymer composites. *Fatigue & Fracture of Engineering Materials & Structures*, 44(4), 1085-1095.
- Crawford, R. J., & Kearns, M. P. 2003.** Introduction to the Rotational Moulding Process. *Practical Guide to Rotary Molding*, Rapra Technology Limited, UK, 26-1.
- Crawford, R. J., & Martin, P. 2020.** *Plastics engineering*. Butterworth-Heinemann.
- Dropik, M. J., Johnson, D. H., & Roth, D. E. 2002.** Developing an ANSYS creep model for polypropylene from experimental data. In *Proceedings of International ANSYS Conference (Vol. 161)*.
- Dean, G. D., & Broughton, W. 2007.** A model for non-linear creep in polypropylene. *Polymer testing*, 26(8), 1068-1081.
- Faizan, M., & Gangwar, S. 2021.** Tensile behaviour of carbon fiber reinforced polymer composite using ANSYS 21. *Materials Today: Proceedings*, 46, 6519-6526.
- Kyzy, B. K., Lanzutti, A., Magnan, M., Rondinella, A., Simonato, M., Furlanetto, R., & Fedrizzi, L. 2021.** Creep study of glass reinforced polypropylene: Effect of temperature and presence of notches. *Engineering Failure Analysis*, 128, 105624.
- Lombroni, R., Giorgetti, F., Calabrò, G., Fanelli, P., & Ramogida, G. 2021.** Using MAXFEA code in combination with ANSYS APDL for the simulation of plasma disruption events on EU DEMO. *Fusion Engineering and Design*, 170, 112697.
- Malika, M., Bhad, R., & Sonawane, S. S. 2021.** ANSYS simulation study of a low volume fraction CuO–ZnO/water hybrid nanofluid in a shell and tube heat exchanger. *Journal of the Indian Chemical Society*, 98(11), 100200.

- Nitta, K. H., & Maeda, H. 2010.** Creep behavior of high density polyethylene under a constant true stress. *Polymer Testing*, 29(1), 60-65.
- Pan, Y., Gao, X., Lei, J., Li, Z., & Shen, K. 2016.** Effect of different morphologies on the creep behavior of high-density polyethylene. *RSC advances*, 6(5), 3470-3479.
- Pozhil, S. N., Menon, N. M., Waigaonkar, S. D., & Chaudhari, V. 2020.** An analytical model to predict the creep behaviour of linear low-density polyethylene (LLDPE) and polypropylene (PP) used in rotational moulding. *Materials Today: Proceedings*, 28, 888-892.
- Vakili-Tahami, F., & Adibeig, M. R. 2017.** Using developed creep constitutive model for optimum design of HDPE pipes. *Polymer Testing*, 63, 392-397.
- YaylaçI, M., Terzi C., & Aycar M. 2019 (a).** Numerical analysis of the receding contact problem of two bonded layers resting on an elastic half plane. *Structural Engineering and Mechanics, An Int'l Journal*, 72(6), 775-783.
- YaylaçI, M., Bayrak, M. Ç., & Avcar, M. 2019 (b).** Finite element modeling of receding contact problem. *International Journal of Engineering and Applied Sciences*, 11(4), 468-475.
- YaylaçI, M., & Avcar, M. 2020.** Finite element modeling of contact between an elastic layer and two elastic quarter planes. *Computers and Concrete, An International Journal*, 26(2), 107-114.
- Zhang, Y., Madenci, E., & Zhang, Q. 2021.** ANSYS implementation of a coupled 3D peridynamic and finite element analysis for crack propagation under quasi-static loading. *Engineering Fracture Mechanics*, 108179.