JOURNAL OF SCIENTIFIC, TECHNOLOGY AND ENGINEERING RESEARCH
Bilim, Teknoloji ve Mühendislik Araştırmaları Dergisi, (2021) - 2(1) : 4-10
ISSN : 2717-8404 *https://dergipark.org.tr/en/pub/jster*

RESEARCH ARTICLE

Structural Analysis of Metallic Pressure Vessels With Weld Sinkage in the Circumferential Joint

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HIGHLIGHTS

- *Weld sinkage type discontinuity is considered here which is occured during fabrication process of pressure vessel. Literatures on the study area are not many and have importance in design of pressure vessel to various engineering field.*
- *Non-linear(geometric and material) FEA carried out in this article.*
- *The stress concetration factor due to cir-seam weld sinkage is reported.*
- *Unintentionally stress discontinuity introduced during fabrication/manufacturing process is studied.*

Keywords:

- Circumferential joint,
- Finite element analysis,
- Nonlinear analysis,
- Pressure vessels,
- Weld sinkage

Article Info:

Received : 16.02.2021
Accepted : 06.03.2021
Published : 21.06.2021

DOI:
10.5281/zenodo.4586360

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GRAPHICAL ABSTRACT

The presence of weld sinkage in cir-seam joint of pressure vessels (cylindrical and spherical) has been investigated in this work. The discontinuity considered here is named as weld sinkage. The corresponding discontinuity stress introduced during fabrication process is analysed. Here only geometric aspects are being considered and the discontinuities are assumed to be free of residual stress. Non-linear finite element analysis (NL-FEA) performed. The vessel material of HSLA 15CDV6 is considered. Graphically the deformations and stress distributions(meridional, hoop and effective) along axial distance are shown. The effective (von-Mises) stress is found at sinkage location around 2 and 4 times higher than nominal stress (stress away from weld sinkage location) for cylindrical and spherical vessel respectively.The results are shown in Figure A.

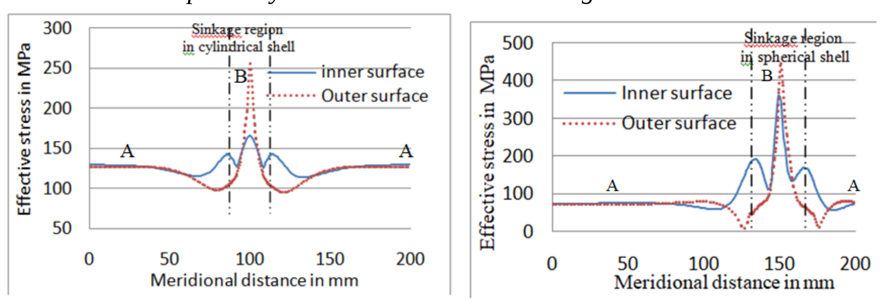

Figure A. The Effective stress distribution in (a) cylindrical and, (b) spherical shell

Aim of Article :*To find the stress concentration factor due to discontinuity stress at weld sinkage location of a pressure vessel.*

Theory and Methodology : *The Non-linear (both material and geometric) finite element method has been used to study the problem.*

Findings and Results: *Results show that the stress concentartion factor is 2 to 4 times for cylindrical and sperical vessel at sinkage location as compared ti nominal stress region(away from discontinuity region).*

Conclusion : *NL-FEA (geometric and material) has been attempted in this work to predict the actual structural behavior of pressure vessel (cylindrical and spherical) segments of equal thickness in presence of sinkage type mismatch in the circumferential weld joint.* ***The*** *effective (von-Mises) stress is found at sinkage location approximately 2 and 4 times higher than nominal stress(stress away from sinkage location) for cylindrical and spherical pressure vessel respectively. This study (weld sinkage) is having importance to pressure vessel design which is common in aerospace, mechanical and chemical engineering sector, which is occurred from manufacturing process. However, these results (stress concentration factor) will be further verified through different thickness of pressure vessel segments with different sinkage radius and its occurrence at cir-seam and long-seam location from fabrication process of pressure vessel. This work can be extended to find the burst pressure of pressure vessel in presence of weld sinkage to find its capacity.*

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Citation:
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HIGHLIGHTS

- *Weld sinkage type discontinuity is considered here which is occured during fabrication process of pressure vessel.Literatures on the study area are not many and have importance in design of pressure vessel to various engineering field.*
- *Non-linear(geometric and material) finite element analysis carried out in this article*
- *The stress concentration factor due to cir-seam weld sinkage in pressure vessel is reported.*
- *Unintentionally discontinuity stress introduced during fabrication/manufacturing process is studied. The obtained results are important in design of pressure vessel with application to aerospace and chemical industry.*

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ABSTRACT

The presence of weld sinkage in cir-seam joint of pressure vessels (cylindrical and spherical) has been investigated in this work. The discontinuity considered here is named as weld sinkage. The corresponding discontinuity stress introduced during fabrication process is analysed. Here only geometric aspects are being considered and the discontinuities are assumed to be free of residual stress. Non-linear finite element analysis (NL-FEA) performed. The vessel material of HSLA 15CDV6 is considered. Graphically the deformations and stress distributions(meridional, hoop and effective) along axial distance are shown. The effective (von-Mises) stress is found at sinkage location around 2 and 4 times higher than nominal stress(stress away from sinkage location) for cylindrical and spherical vessel respectively.

Keywords: *Circumferential joint, Finite element analysis, Nonlinear analysis, Pressure vessels, Weld sinkage*

I. INTRODUCTION

In the aerospace, nuclear power, oil, chemical, and many other industries pressure vessels are widely used. In fabrication, various segments are joined together by welds or some other means to form complete pressure vessels. Certain regions of pressure vessels were exist, where structural continuity cannot be satisfied by the membrane forces alone. Such regions are called as discontinuity regions. The stress associated in these region is termed as discontinuity stress. Presence of discontinuities in thickness, radius and slope in the manufactured product causes additional bending stress. In the discontinuity region the stress distribution may change. It is desirable to reduce the number and magnitude of discontinuity to a minimum. In the context of effects of distortion at welded joints, the distortions considered are mismatch [1-8], weld sinkage [9] (peaking or angular mismatch), slope discontinuities and out of roundness in pressure vessels. Literature studies show that there is very limited work available. In the present work, to predict the structural behavior of pressure vessel segments of equal thickness with weld sinkage type discontinuity is considered and corresponding discontinuity stress introduced during fabrication process is analysed. Further, here only geometric aspects are being studied and the discontinuities are assumed to be free of residual stress. NL-FEA[10] is carried out to model the pressure vessel with presence of sinkage type weld mismatch. The stress concentration factor due to weld sinkage is reported. These results are very much useful as a design guide lines for researchers and design engineers working in pressure vessel fields.

II. WELD SINKAGE[9] (ANGULAR DISTORTION)

Weld sinkage [9] is the term used to describe the meridional slope discontinuity of the general shape. This is symmetric, around the circumference of the shell and also with respect to its lowest point. This type of discontinuity is frequently occurring during welding. The geometric aspect of the discontinuity is considered here and shown in Fig.1.The shell is considered stress free before the application of the first pressure loading. A cylinder subject to peaking distortion at the welded joint could be treated as a special case of a noncircular cylinder(Fig.1).

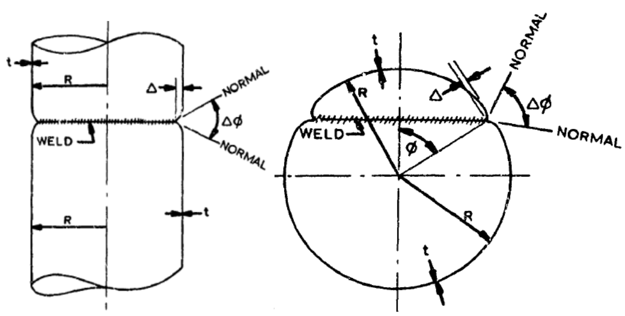

Figure 1. Typical weld sinkage in cylinder and sphere[9]

The main geometry parameters of sinkage [9] are sinkage length (L), sinkage depth (Δ) and angular change (Δφ) and shown in Fig. 2.

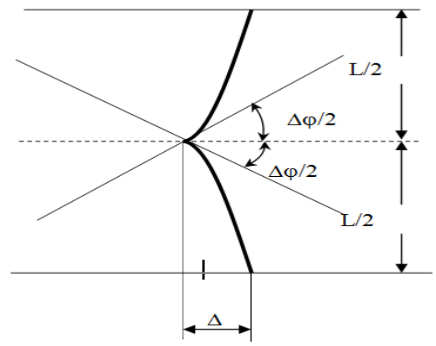

Figure 2. Sinkage geometry parameters

The two other parameters considered for the weld sinkage [9]are pressure nonlinearity parameter (ρ) and geometry factor (μ) and given in equ.(1) and equ.(2) respectively. The parameter is related to the structural geometry only as follows.

$$\mu = \frac{0.55}{\Delta}\sin\left(\frac{\Delta\emptyset}{2}\right)\sqrt{Rt} \tag{1}$$

$$\rho = \frac{P}{\frac{2}{\sqrt{3(1-\upsilon^2)}}E\left(\frac{t}{R}\right)^2} \tag{2}$$

III. FINITE ELEMENT ANALYSIS

NL-FEA (material and geometric) has been carried out[3,4] on pressure vessels(cylindrical and spherical) having weld sinkage[9] in the cir-seam (circumferential direction) joint as shown in the Figure 3. R is the radius of cylinder and sphere. t is the thickness of shell. R_T is the sinkage radius or toroidal meridional radius. The geometric details of the vessels used are given in Table I and Table II.

An axi-symmetric model with PLANE 42 element of Ansys[10] is used for FE idealization. The convergences of the results were verified by analyzing the models with different mesh density.

The material used for the vessel is HSLA 15CDV6 [3,4] having Young's modulus (E) 206010 MPa, Poisson's ratio of 0.3,yield strength 834 MPa and ultimate strength 0f 981 MPa.

Internal pressure is estimated by considering the pressure nonlinearity parameter as 0.05[9]. The length of vessel is considered here such that the discontinuity stress disappears and the membrane stress exists away from the junction (i.e. sinkage location). Further the stress away from discontinuity region becomes nominal stress (hoop=PR/t; meridional PR/2t for cylindrical shell and hoop=meridional stress = PR/2t for spherical shell)[11].

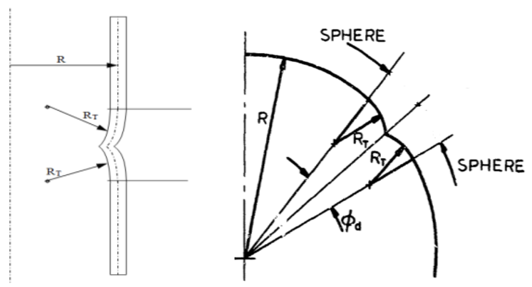

Figure 3. Geometry of cylindrical and spherical pressure vessel having weld sinkage[9]

The boundary conditions are applied on the shell as follows. One end of the longitudinal edge of cylindrical shell vessel is constrained in the axial direction to avoid rigid body motion and at the other edge end force corresponding to closed end condition is applied as a pressure load [3].

In spherical pressure vessel symmetric boundary conditions are applied at symmetry plane. The loading in vessel is internal pressure load which is applied on inner surface. NL-FEA (material and geometric) is performed.

Table I. Geometric detail of cylindrical pressure vessels having weld sinkage[9]

t_a/t_b	R	t	L	Δ	$\Delta\varphi$	ρ	μ
1	216	2.5	30	1.626	24.7	0.05	1.68

Table II. Geometric detail of spherical pressure vessel having weld sinkage

t_a/t_b	R	t	L	Δ	$\Delta\varphi$	ρ	μ
1	216	2.5	17.2	8.0	55.2	0.05	0.74

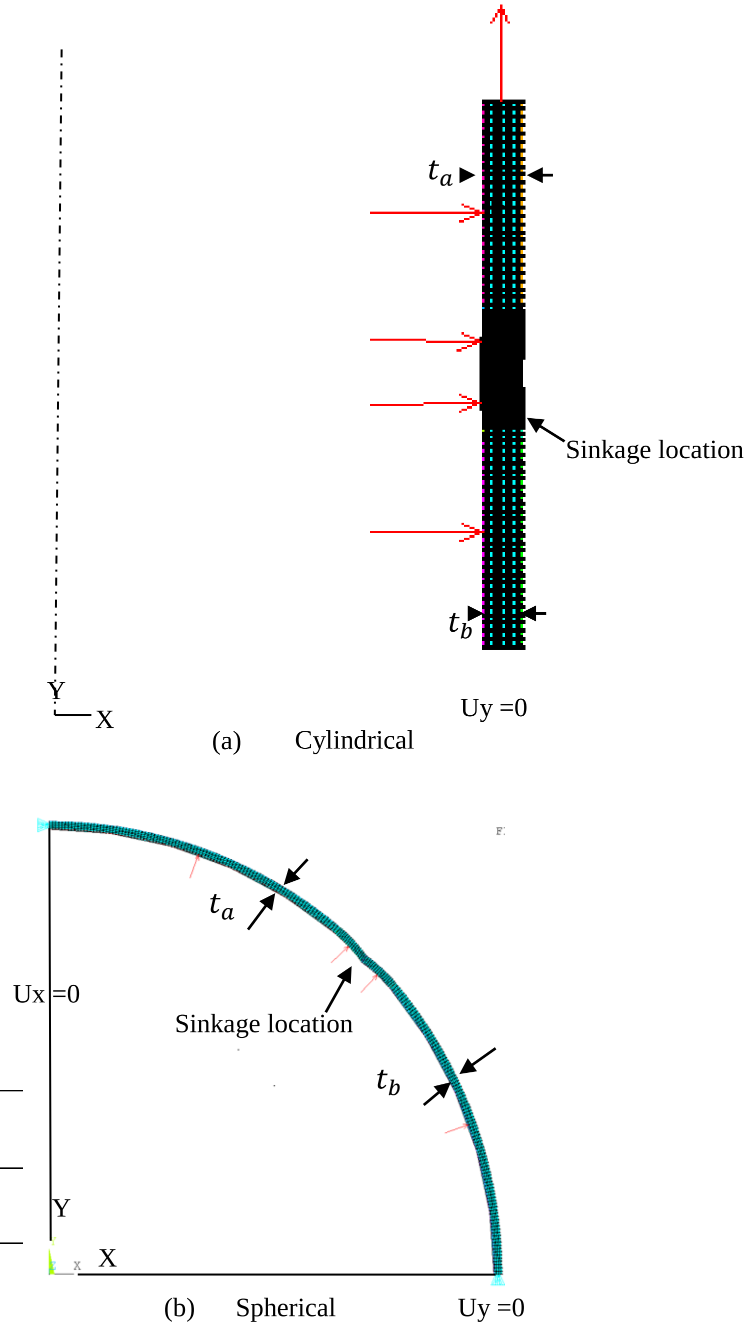

Figure 4. Finite element model showing weld sinkage in (a) cylindrical and (b) spherical vessel at cir-seam joint

III. RESULT AND DISCUSSIONS

Stress distributions and deformations were plotted along axial distance for both vessels with sinkage at cir-seam joint. Figures 5 and 6 show the distribution of meridional stress, hoop stress and effective stress in a cylindrical vessel. The stress distributions are found to be symmetric with peaks at the weld. The discontinuity stresses are diminishes and membrane

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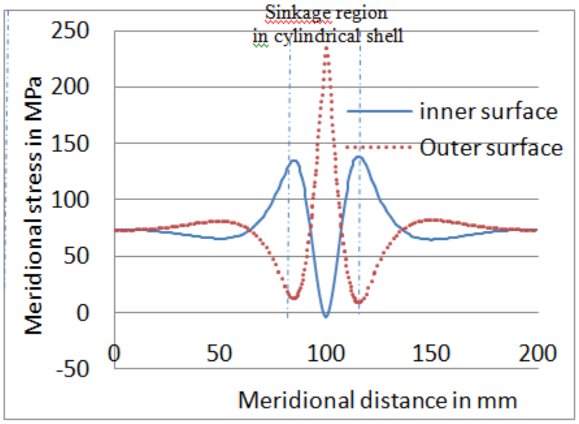
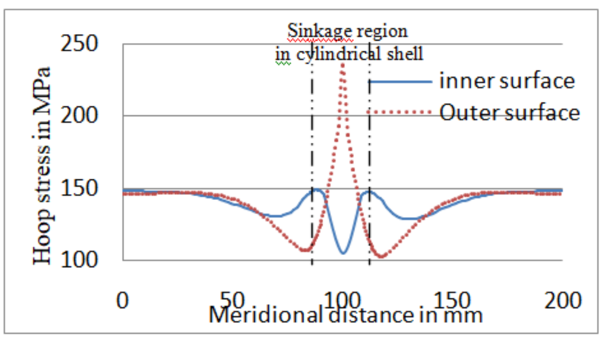
stress exists away from the joint. The deformations in axial and radial direction are also given for cylindrical pressure vessels in Figure 7.

A. *Cylindrical Pressure Vessel*



(a)



(b)

Figure 5.(a) Meridional stress and (b) Hoop stress distribution for cylindrical pressure vessel

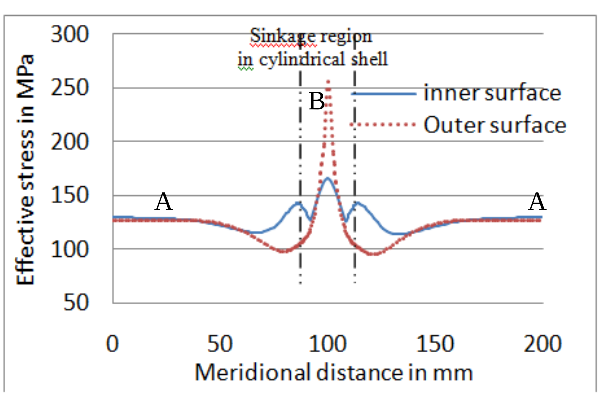
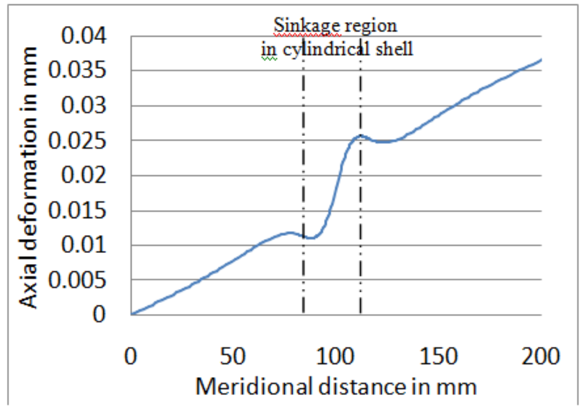
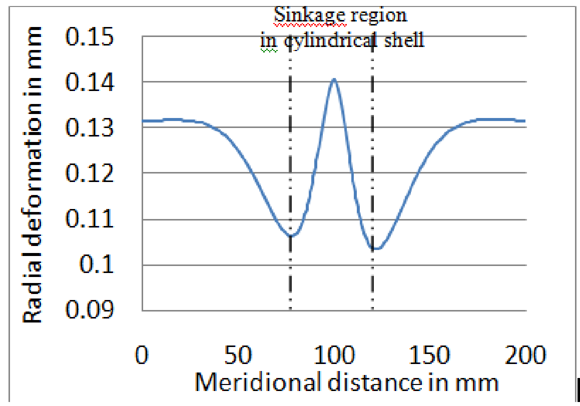


Figure 6. Effective stress distribution for cylindrical pressure vessel



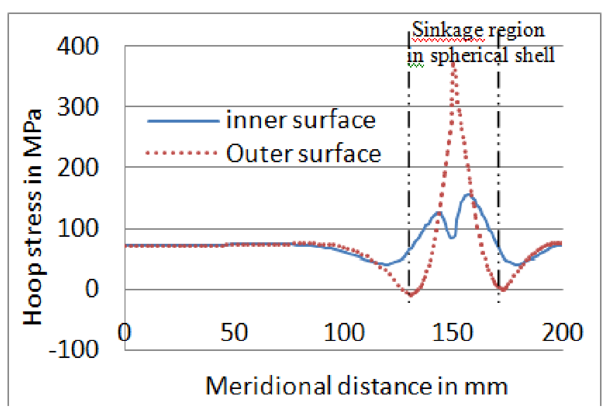
(a)



(b)

Figure 7.(a) Axial and (b) radial deformations of cylindrical pressure vessel

B. *Spherical Pressure Vessel*



(a)

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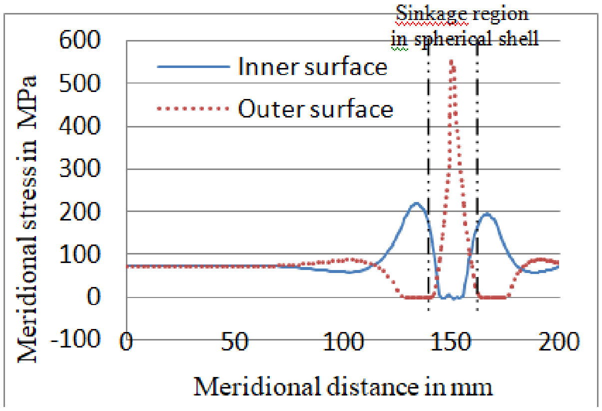

(b)

Figure 8.(a) Hoop and (b) Meridional stress distribution for spherical vessel

Figures 8-9 give the meridional, hoop, effective stress distributions at the joint of spherical pressure vessel having sinkage. It is seen from that stress distribution curves of similar trend as that of the cylindrical vessel. The peak effective stress at sinkage location (B) is around 2 times of nominal stress region (A) in cylindrical shell is found as shown in Figure 6.

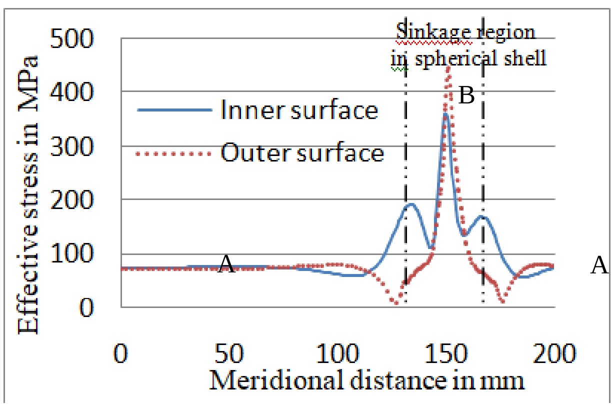

Figure 9. Effective stress distribution in spherical shell

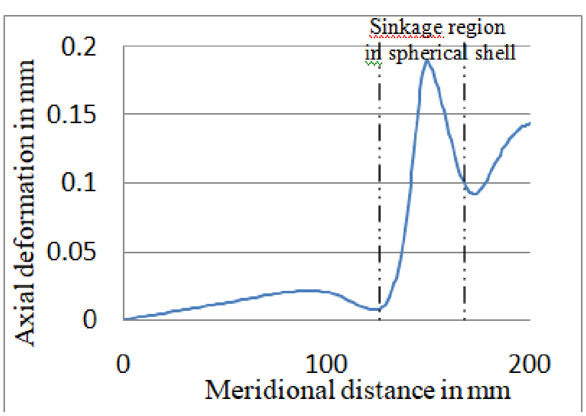

Figure 10. Axial deformation distribution for spherical shell

The peak effective stress at sinkage location (B) is approximately 4 times of nominal stress region (A) in spherical shell is found as shown in Figure 9. The axial deformation is shown in Figure 10.

IV. CONCLUSION

NL-FEA (geometric and material) has been attempted in this work to predict the actual structural behavior of pressure vessel (cylindrical and spherical) segments of equal thickness in presence of sinkage type mismatch in the circumferential weld joint. This type of weld sinkage is unexpectedly occurred from fabrication process. Non-linear finite element results were verified by analyzing the models with different mesh density through the convergences study. The location of the peak stress is found through FEA and found the effective stress at sinkage location is 2 and 4 times approximately higher than nominal stress for cylindrical and spherical shell respectively. The trend of stress distribution along the axial distance of spherical pressure vessel is similar to that of cylindrical pressure vessel. The discontinuity stresses are found to be symmetric on either side of the weld sinkage joint of both vessel (cylindrical and spherical).

However, these results (stress concentration factor) will be further verified through different thickness of pressure vessel segments with different sinkage radius and its occurrence in cir-seam and long-seam location from fabrication process of pressure vessel. This work can be extended to find the burst pressure of pressure vessel in presence of weld sinkage to find its capacity.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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