Operation of process equipment with crack-like defects

S I Valeev* and I E Kharlamov
Kazan National Research Technological University, Kazan, Republic of Tatarstan, Russian Federation

*svi73@mail.ru

Abstract. Analysis of the ‘layer separation’ defect of the base metal depending on the depth of its occurrence on the further safe operation of process equipment is carried out. The calculation is performed by the finite element method using ANSYS software package. The obtained results enable one to conclude that the layer separation does not have a significant effect on the bearing capacity of the equipment, while it is local and not being distributed.

The lifetime of a large number of process equipment in many industries has reached the design one, is approaching or exceeds it [6,8,9,13].

As analytical studies show, the operation of containers and apparatuses that have fulfilled their standard service life is potentially dangerous. Due to impossibility and inappropriateness of replacing the entire stock of such equipment with a new one, the tasks of justifying its service life extension and ensuring safe operation for this period arise [1,3,10,11].

Containers and apparatuses, in particular, welded and cast ones, may initially contain extended defects. Among many defects of this type, a defect called ‘layer separation’ stands out [3, 10, 12].

Layer separation can appear both at the operational stage and may be initially present in the metal of process equipment, unnoticed during the incoming inspection [10,12].

In the general case, layer separation is a violation of the continuity inside the rolled metal, which is rolled up large defects of the ingot (deep shrinkage shells, shrinkage porosity, clusters of bubbles or non-metallic inclusions). A characteristic feature of layer separation is that the surface of discontinuity is parallel to the rolling plane, the rolled clusters of non-metallic inclusions give an inner layer separating the sheet or profile into two, three or more parts.

Among the non-destructive testing methods [3, 6], the most acceptable for detecting layer separation is the ultrasonic method, despite its relative complexity. For example, the method of color flaw detection does not allow to reveal layer separation due to the fact that the defect does not come to the surface; the method of X-ray gamma-graphing is uninformative, since the defect is parallel to the inner and outer surfaces of the wall; eddy-current and magnetic control methods do not provide complete information, since the defect is not located in the subsurface layer, but in the wall thickness. However, at an early stage of layer separation, difficulties can arise in interpreting the results and with ultrasonic testing.

As noted earlier, every hundredth container and apparatus for the examination period has layer separation of the base metal or a welded joint. A wide range of process equipment is susceptible to separation type defects - tanks, heat exchangers, columns, separators, gas holders, etc.
Typically, the operation of such equipment is permitted provided that the defective area is repaired by welding or a periodic inspection of the defective area is conducted by non-destructive methods in order to control the increase in the separation size, if the separation size and location do not allow repair [2,3,10,12]. Periodic monitoring of the process is expensive and time-consuming, especially if it is impossible to withdraw equipment from the engineering process.

When deciding on the further operation of equipment with a layer separation defect, it is necessary to take into account first of all its depth and direction.

The aim of this work is to determine the possible safe operation of petrochemical equipment’s elements with layer separation of the base metal, taking into account its depth.

The known experimental data [7] do not enable us to provide a quantitative assessment of the fracture responses of an element having a layer separation. This task presents a certain difficulty for analytical methods. Promising in this regard are numerical methods, among which the leading role is given to the finite element method.

When assessing the safe operation of an equipment item with layer separation, it is necessary, first of all, to assess the possibility of brittle fracture or resistance to brittle fracture, since fractures of this type are especially dangerous. The main criterion for the analysis of brittle and quasi-brittle fractures (operating temperature does not exceed the first critical temperature) is the SIF stress intensity factor [4,10,12,13].

The layer separation is a crack-like defect. It differs from other defects of this type (normal tearing cracks) in its special arrangement in the metal. As noted above, this defect is parallel to the surface of the element wall. The forces of longitudinal and transverse shear significantly prevail over the forces of normal separation of the coasts of the layer separation.

To confirm this statement, a finite element model of the shell with layer separations located in it was studied. The shell dimensions and internal pressure are constant.

The calculation of the stress-strain state and the calculation of stress intensity factors were performed by the finite element method using ANSYS software package [5,10,13]. A half-shell model with a record of the corresponding boundary conditions on the plane of symmetry was considered. To simulate the reaction of the bottoms, corresponding tensile stresses were applied to the end planes. Separations were modeled at different depths. The separations were modeled parallel to the shell surface. The influence of stress concentrators (seams, fittings, supports, etc.) was not considered. To create the correct mesh in the region of the separation front, 2-D elements with displaced central nodes (to implement the shape function with the root feature) PLANE82 and 3-D SOLID186 elements with the addition of contact elements CONTA174 and TARGE170 were used.
Figure 1. The calculated values of KI stress intensity factor for various separation depths.

Figure 2. The calculated values of KII stress intensity factor for various separation depths.
Figure 3. The calculated values of KIII stress intensity factor for various separation depths.

A nonlinear contact static problem was solved without taking into account plastic deformations in the crack front zone.

Figures 1,2,3 show the calculated values of the stress intensity factors (SIF) KI, KII and KIII for 7 points along the front of the round separation located every 30 degrees from 0 to 90 degrees relative to the axis of the separation, passing along the normal to the plane through its center. The values were obtained at various layering depths for ratios of the depth to wall thickness from 1/5 to 4/5.

As can be seen from the calculations, the maximum values relative to other stress intensity factors are reached by the stress intensity factors of the second type — KII (longitudinal shear crack) located closer to the inner wall of the shell.

The obtained results show that, ceteris paribus, stress intensity factors of the second type KII prevail, which in turn reach maximum values for separations located closer to the shell’s inner wall.

The conducted studies confirm [10,12] that the separation does not have a significant effect on the bearing capacity of the equipment, while it is local and not being distributed.

References
[1] Federal Law dated 21.07.1997, No. 116-FL ‘On Industrial Safety of Hazardous Production Facilities’, as amended;
[2] Order of the Federal Service for Environmental, Technological and Atomic Supervision dated 11.03.2013 No. 96 ‘On Approval of Federal Norms and Rules in the Field of Industrial Safety ‘General Rules of Explosion Safety for Explosive Chemical, Petrochemical and Oil Refining Industries’
[3] RD 03-421-01 Guidelines for diagnosing the technical condition and determining the residual service life of vessels and devices of the State Unitary Enterprise ‘Scientific and Technical Center ‘Industrial Safety’, Approved by the Resolution of the Gosgortechnadzor of Russia dated 06.09.01 No. 39
[4] PNAE G-7-002-86 Standards for calculation of the strength of equipment and pipelines of nuclear power plants. Moscow, ENERGOIZDAT, 1989.
[5] Kaplun A.B. ANSYS in the hands of an engineer. Practical Guide / A.B. Kaplun, E.M. Morozov, M.A. Olfer’eva // M.: Editorial Publ., URSS. - 2003. - 272 p.

[6] Installation, technical diagnostics and repair of the main technological equipment of chemical industries and oil and gas processing: a textbook / I.I. Ponikarov [et al.]. - Kazan: Izd-vo Akademii nauk RT Publ., 2018. - 798 p.

[7] Cherepanov G.P. Mechanics of destruction / G.P. Cherepanov, E.R. Ershov. Mashinostroenie Publ.- 1977. -224 p.

[8] Anna Ponikarova, Maksim Zotov, Sergey Ponikarov, Model of control of reability using the parameters of survivability in terms of innovation / MATEC Web of Conferences. 2019, vol. 298, 00105, pp. 1-8

[9] Anna Ponikarova, Maksim Zotov, Irina Ponikarova. Determining the level of structural survivability to control the reliability of innovative economic systems / MATEC Web of Conferences. 2019, vol. 298, 00104, pp. 1-7

[10] Kharlamov I.E., Valeev S.I. Calculation of strength of shell suffering exfoliation / Chemical and Petroleum Engineering, Vol. 54, Nos. 3-4, pp. 278-282, July 2018

[11] Ponikarova A.S., Zotov M.A., Kadeeva E.N. Balanced management of innovative risks in the process of innovative development / IOP Conference Series: Materials Science and Engineering. - 2020. - vol. 709. 033091.- pp. 1-7.

[12] Valeev S.I., Kharlamov I.E. Forecasting the resource of bulk-capacity equipment with crack-like defects / Materials Today: Proceedings, -Vol. 19, -Nos. 5, -2019, - pp. 2488-2490.

[13] Valeev S.I., Kharlamov I.E., Determination of powerful active zones of petrochemical equipment / IOP Conference Series: Materials Science and Engineering, 537(2019)032059.