Chapter

How Impact the Design of Aluminum Swaging Circle Fitting on the Sealing for Piping Systems: Analytical and Numerical Model

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Abstract

Installation and repair of hydraulic installations are carried out by joining the pipes in the field. Pipe connections in aviation are made in a very narrow space and field. For this reason, fitting swaging method is used to connect the fittings to the pipes with a hydraulic hand tool. The basis for developing a swaging tool is knowledge of the design parameters for the plastic deformation of the swaging circle fitting. In addition to the design parameter, pipes have to be joined in cryogenic vacuum conditions, which require sealing in such sensitive and harsh conditions. In this study, the effect of swaged circle fitting designs on tightness and strength was determined and different swaging methods were examined for its improvement. Different geometric swaged circle fittings are designed and analytical and numerical models are solved. The solution results obtained show the characteristic effect of the fitting swaging analysis methodology and the swaged circle fitting design on the sealing of the pipe joint. The innovation is mainly the effect of the swaging circle connection design on the sealing of the pipe joint. With the finding in this work, it is now possible to develop or develop new tools for engineered swaging circle fitting.

Keywords: pipe joining, sleeve design, swaging ring, sleeve swaging method, pipe connection

1. Introduction

The structural engineers faced many challenges to safely and durably design and build the budget-consuming projects. The loadings may damage the piping structures or disturb their normal operations whenever their magnitudes reach the strength limits of the structure material [1].

Mostly the structural engineers performed three-dimensional (3D) finite-element analyses to investigate the behavior of buried pipe subject to strike-slip fault movement in dry sand and, more realistically, in partially saturated sand [2].

Some literature presents specific methods and algorithms for evaluating potential damage zones of pipe joints that can be used to make decisions to ensure the safety of use of hazardous production systems that also concern human life in the gas-oil sector during the draft and detailed design and later use stages [3].

Design analysis engineers recommend to specify mechanical closure and fatigue conditions considering stress and amplitude depending on swage parameter and material for using swaged fittings to joining in structural engineering and mechanical handling [4].

In some load cases, to obtain more realistic results from design analysis for structural systems, it is necessary to determine or to define suitable fastener stiffness values in their connections [5].

It is necessary to propose an analytical or numerical useful method for the practicing engineers in the rational design of pipe connections in detail designing and structural analysis [6].

The most critically part of a piping is they are connections, each other or to equipment. Piping solutions using non-welded connections and cold bent piping offer significant value through reductions in fabrication and commissioning time, while improving workplace safety. The benefits of non-welded piping technology are ranging from reduced preparation and inspection time to a safer work environment [7].

Different methods are used to join the tubes. One of them is rotary swaging, in them the rotation energy changed to thermal friction energy and the fitting is swaged on the pipe with approximately 100% sealing [8].

The swaging as a joining method is used today in most crucial industries including the military, automotive, and medical. Within the military industry, swaging is used to form items such as gun barrels and anti-tank rocket tips. Fittings are also swaged into cable. Countless auto parts and systems, such as distress alert brake cables, steering components, and powertrains, are produced by rolling. In the medical sector; subcutaneous needles, catheter tape assemblies and optical parts and assemblies are the first to come to mind as products produced by rolling the same. In the energy sector; heater elements, heat conductive materials and zirconium profiles can be listed (items that the renewable energy industry relies upon), can be expertly machined using swaging machines. In aerospace; by swaging, the aerospace industry is assured of high-quality control rods, wire rope cable assemblies, and fluid transfer tubing [9].

It is useful for swaging tube and pipe made from the manufacturing industry's most common material (steel) and it's also suitable for stainless steels, aluminum, titanium alloys.

Also, swaged pipe in pipe construction has been increasingly used for offshore pipeline system. The end connection, produced by plastering and rolling, is transmitted to the outer tube by a cold deformation process and then connected to the inner tube. The twin welded piping system provides excellent thermal insulation [7].

In any case, literature studies have shown how important fasteners are to structural design engineers. Piping designs are generally calculated with 16 bar and below, and such connections are designed as removable flange or screw connections. In screw connections in such systems, rubber or metal plastered intermediate element between the screw and the nut provides both the connection and the sealing [10].

Connections in pipe systems operating under high pressure are produced using rubber or metal unions produced using the swaging method. Such connections are designed and tested at 1.5 times the working pressure and at burst pressure. Piping systems used in aerospace are produced from either stainless steel or mostly aluminum alloy pipes. In addition to rubber plastic piping, and also their tightness is tested by performing tests such as vibration tests under conditions far above operating conditions [11].

Although there is not much in this field (ring swaging pipe connection), design and analysis studies have been carried out [12].

As can be seen in the swaging type A in **Figure 1**, both the direct connection of the two pipes and the connection of the fittings with the pipe can be done with the design of the swaging circle fitting (Sleeve), which is one of the main inspection elements of the study. The pipes to be connected can also be of different materials; however, different swaging parameters have to be determined in this case. These connections, as in welded connections, are expected to be made to withstand more pressures than the pipe itself. The design of the sealed swaging circle fitting pipe significantly affects the mechanical strength and tightness of the joint. As can be seen in **Figure 1**, the area to be compacted is designed as inclined and undulated in the axial direction; this prevents it from being pulled in the axial direction. Likewise, the swaging circle fitting creates an obstacle to the tangential rotation of the pipe in the fitting with waves in the circumferential direction. In addition, two internal circumferential grooves have been designed to provide greater sealing by placing an O-Ring in the ring.

In **Figure 1**, a cut-out view of the A-type fitting is given. Compression is applied in two steps by pressing the first pipe from the right and then the pipe from the left towards the center in a radial direction, so that the plastering circle counts the plastic displacements. Pipes and the middle part of the fitting exposed to pressure load does not exceed elastic loading. When pipes are of different materials, different swaging parameters must be applied from right and left.

In **Figure 2**, there is a cross-sectional view of the B type. The swaging fitting is axially and radially pressured to the first pipe from the right and then from the left to the second pipe, resulting in plastic deformation. Pipes and middle part of c fitting exposed to pressure load does not exceed elastic loading. When pipes are of different materials, different swaging parameters must be applied from right and left.

In **Figure 3**, there is a cut view of the Type C. The swaged fitting tube piece is clamped radially to the first tube from the right and then from the left to the second tube simultaneously with two pressure booster wedge rings. In the meantime, sealing is tried to be achieved by creating plastic deformation. Pipes and middle part of circle form fitting exposed to pressure load does not exceed elastic loading. When pipes are of different materials, different swaging parameters from right and left and different riser fitting designs must be applied.

In this study, the swaging circle fitting that will work without leakage under high or low pressures is tightened with each of the three different methods shown under the previous introducing, and the ability to join 2 aluminum alloy pipes is modeled and analyzed by analytical and numerical methods. Different types (Types A, B, and C) designs of aluminum alloy swaged strap fastener were designed in 3D

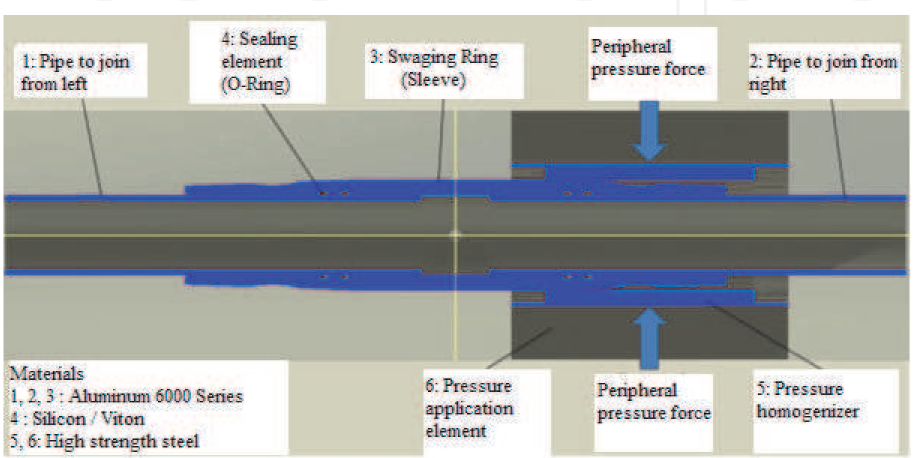

Figure 1.
A type swaging circle fitting; pressure equalizer design features in the radial direction [13].

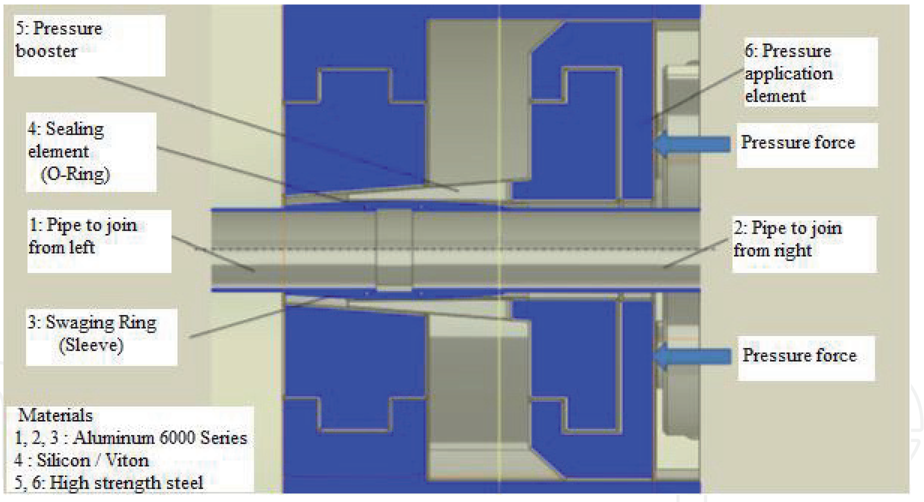

Figure 2.
B type swaging circle; radial swaging designs with pressure against axial tension and pressure booster [13].

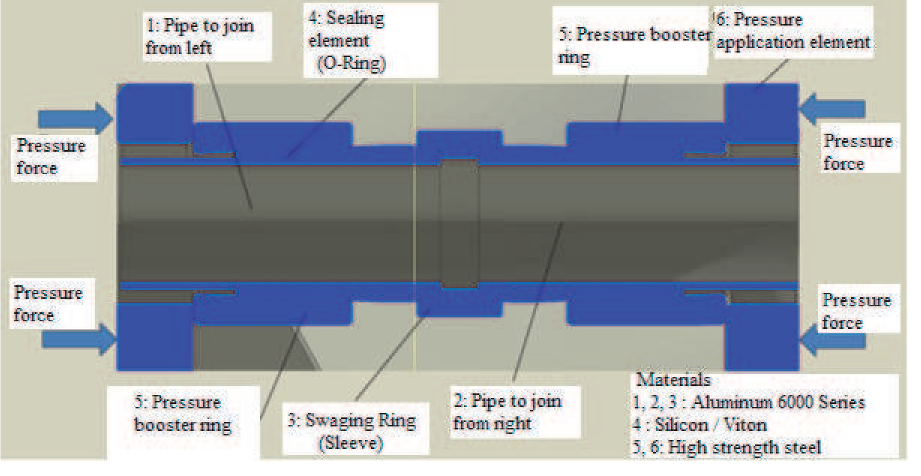

Figure 3.
Swaging type C; radial swaging by tightly compressing the pressure booster (wedge) fitting to the swaging circle fitting by axial pressure force [13].

and mathematically solved using the finite element method. Due to the nature of the numerical method, swaged circle pipe parts and pipes that are connected to each other and may be in different materials are subject to elastic–plastic (bi-linear material definition) deformations. For this reason, the numerical solution could only be realized with a non-linear method [14–16]. In addition, since the material is exposed to plastic pressure and there is friction between the elements, the solution with the non-linear method becomes inevitable again [14, 16]. The nonlinear solution of the mathematical numerical model was carried out using the finite element method (FEM) with the help of a commercial program on the computer. Different swaging circle fitting designs were analyzed and compared, and the connection has been improved by optimizing with swaging circle fitting design changes.

The numerical method proposed in this study are useful for the practicing engineers in the rational design of pipe connections in detail designing and structural analysis.

2. Analytical design of swaging circle fitting

The swaging circle fitting principle basically relies on mechanical-elastic deformation of the fitting with the external pressure load and also subjecting the inner connection pipe to elastic–plastic deformation.

Figure 4 shows the principle of elastic–plastic deformation applied to the inner pipe and itself by applying pressure to the swaging circle fitting.

In general, stresses occur in the circumferential and radial directions in a pipe loaded under an externally applied pressure. Its radial stress is equal to the applied pressure on the pressure surface and 0 at the other inner surface. Ratio of pipe inner radius to thickness is in the thin pipe class $r_i/s > 5$, calculations are made according to the middle radius and very small variation in thickness can be ignored [17]. Based on this acceptance, the centrifugal tension equals half the pressure:

$$\sigma_r = \frac{p}{2}; s \ll r_m \tag{1}$$

Here: σ_r [MPa]: centrifugal tension,
p [MPa]: pressure applied,
d_a [mm]: outer diameter of the pipe,
s [mm]: pipe thickness,
$r_m = \frac{d_a - s}{2}$ [mm]: middle radius of the pipe.

Figure 5 shows the circumferential tension σ_{tan} and other parameters occurring under the pressure applied on the pipe. Accordingly, the following equation is written in accordance with the principle of equality of forces in the horizontal direction:

$$\rightarrow \sigma_{tan} = p\frac{r_m}{s} \tag{2}$$

Here: σ_{tan} [MPa]: circumferential tension,
p [MPa]: pressure applied,
D_m [mm]: medium diameter of the pipe,
s [mm]: pipe thickness,
$r_m = \frac{D_m}{2} = \frac{d_a - s}{2}$ [mm]: medium radius of the pipe.

Thus, when the equivalent tension is geometrically collected, it is found as follows:

$$\sigma_E = \sqrt{{\sigma_{tan}}^2 + {\sigma_r}^2 - \sigma_{tan}\sigma_r}$$

$$\sigma_E = \sqrt{\left(p\frac{r_m}{s}\right)^2 + \left(\frac{p}{2}\right)^2 - p\frac{r_m}{s}\frac{p}{2}}$$

$$\sigma_E = p\sqrt{\left(\frac{r_m}{s}\right)^2 + \frac{1}{4} - \frac{r_m}{2s}} \tag{3}$$

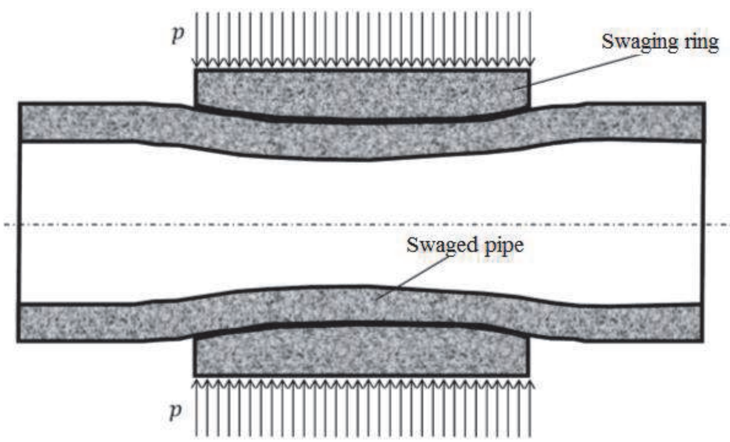

Figure 4.
Swaging principle with swaging circle fitting (sleeve) [13].

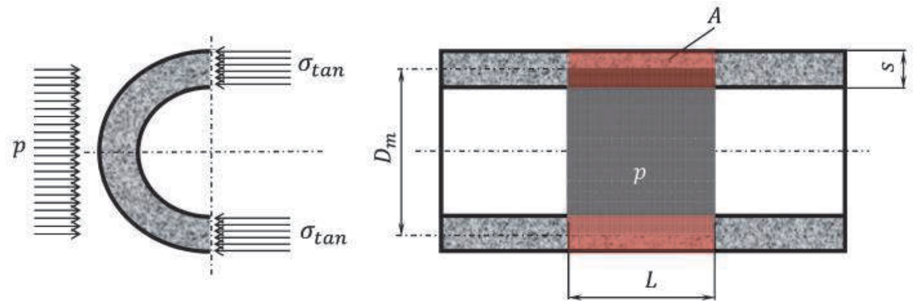

Figure 5.
Peripheral (tangential) stress caused by the pressure pulse [13].

Since the pipe is applied with a minimum degree of yield tension, the least required minimum pressure for this is found by the following formula:

$$p_{min} = \frac{R_{p0,2}}{\sqrt{\left(\frac{r_m}{s}\right)^2 + \frac{1}{4} - \frac{r_m}{2s}}} \tag{4}$$

$$\sigma_{tan}A = pD_mL \rightarrow \sigma_{tan}2sL = pD_mL$$

$$\rightarrow \sigma_{tan} = \frac{pD_mL}{2sL}$$

Here: p_{min} [MPa]: required minimum pressure,
$R_{p0,2}$ [MPa]: yield tension.
Example: Swaging circle fitting: R-29,4x2–6061-T6;
Yield value: $R_{p0,2} = 240$ MPa.
$\rightarrow r_{m,a} = \frac{d_a - s}{2} = \frac{29,4-2}{2}$ mm = 13.7 mm; medium radius of the swaging circle fitting.

$$\rightarrow p_{\,min\,,a} = \frac{240\ \text{Mpa}}{\sqrt{\left(\frac{13,7}{2}\right)^2 + \frac{1}{4} - \frac{13,7}{2\bullet 2}}} = 33,7\ \text{MPa} = 337\ \text{bar}$$

Inner pipe: R-25,4x0,75–6061-T6;
Yield value: $R_{p0,2} = 240$ MPa.
$\rightarrow r_{m,i} = \frac{d_{a,i} - s_i}{2} = \frac{25,4-0,75}{2}$ mm = 12, 325 mm inner pipe medium radius.

$$\rightarrow p_{\,min\,,i} = \frac{240\ Mpa}{\sqrt{\left(\frac{12,325}{2}\right)^2 + \frac{1}{4} - \frac{12,325}{2\bullet 0,75}}} = 14,8\ MPa = 148\ bar$$

Total required minimum pressure: $p_{min} = p_{\,min\,,a} + p_{\,min\,,i} = 33,7\ \text{MPa} + 14,8\ \text{MPa} = 48,5\ \text{MPa}$.

In order to create not only elastic but also permanent plastic deflection in compressed pipes, it is recommended to apply a minimum pressure of more than 30% to the swaged flat fitting. Example: $p = 1,3p_{min} = 1,3\bullet 48,5\ \text{MPa} = 63,0\ \text{MPa}$.

Listed below are the reasons for the design features marked a to d in **Figure 6** that correspond to the requirements of the ring:

a. In principle, as shown in **Figure 4**, the deformation of the tube will be greater in the middle and decrease parabolic towards both sides of the ring.

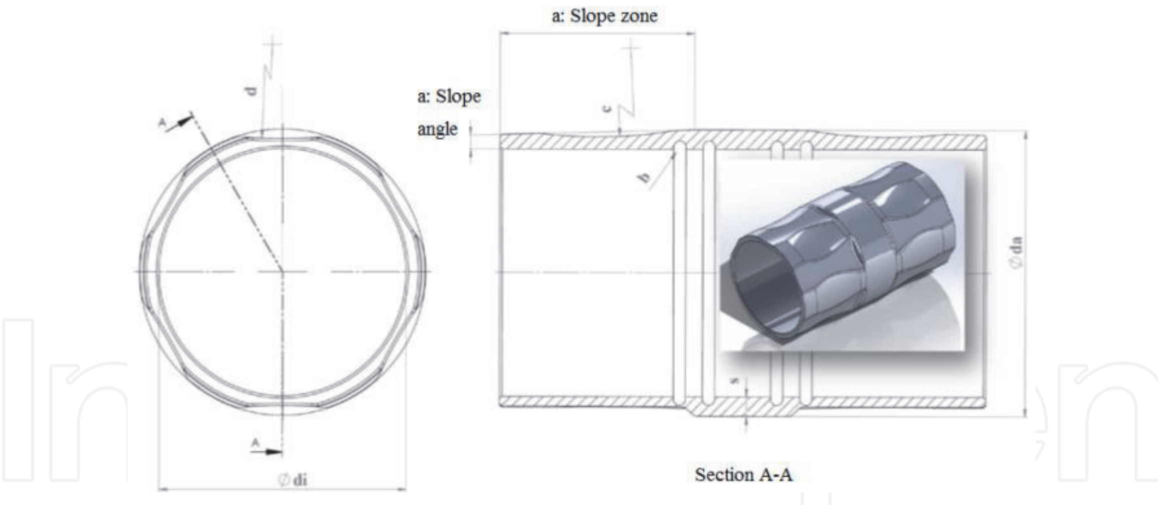

Figure 6.
Swaging circle fitting design [13].

Accordingly, the highest stresses in the inner tube will not be in the middle region, but in the region corresponding to the bottom of the fitting edge. Homogenizing the stress requires homogenizing the plastic deformation, requiring a more convenient beat circle connection. For this, a very small slope ($<1.5°$) is given on the outer surface of the ring.

b. A circumferential groove is made for the inner diameter of the fitting for 2 sealing elements (O-Rings) in each leakage direction.

c. In the axial direction, a circumferential groove is formed in the middle of the pressure zone of the fitting to make it difficult for the pipe to exit the ring. When the fitting is tightened, a similar plastic deformation is made in the inner pipe, making it difficult for the inner pipe to come out of the fitting in the axial direction.

d. The circumference of the pressure area of the fitting is not circular but rather wavy, making it difficult for the tube to exit the fitting in the circular direction of rotation. When the fitting is tightened, a similar plastic deformation occurs in the inner tube and the inner rod is prevented from rotating in the ring.

The design features of the swaged circle fitting are illustrated in 3D in **Figure 6** and described above. The analyzes of these different design features are analyzed numerically using the finite element method (FEM).

3. Numerical solutions and interpretations of mathematical models

The flat swaged circle fitting described in **Figure 6** and the other 4 swaged circle fittings from A to C are designed in 3D with commercial program (SolidWorks® 2013). The described 3D Models (A, B, and C) are transferred to the numerical commercial solver program (ANSYS Workbench® 14.5) using the Finite Element Method and analyzed by adding physical parameters.

In this study, FEM-Analysis was performed by considering 4 different geometric variations of swaged circle fitting. These have the following geometric design features shown in **Figure 6**:

- Pattern “Flat” swaged circle fitting
- In Model “A”, small curved swaged circle fitting
- In “B” model; Small curved swaged circle fitting with inner groove for sealing
- In Model “C”, small curved, axially waved swaged circle with inner groove for sealing

The Finite Element Models of 4 different fitting designs is shown in **Figure 7** (in Mesh form).

Figure 8 shows three separate stepwise loading cases applied in all of the Finite Element Models in Simulation.

The Finite Element Models are solved numerically elastically-plastically by non-linear method. The pictures below show the deformation values of these solutions for the 3 loading cases described above. In particular, the high percentage of plastic deformation and homogeneity indicates the quality of the connection.

In the “Flat” Model in **Figure 9**, since plastic deformation is not lagging behind when the flat swaging circle fitting is released after being subjected to elastic–plastic

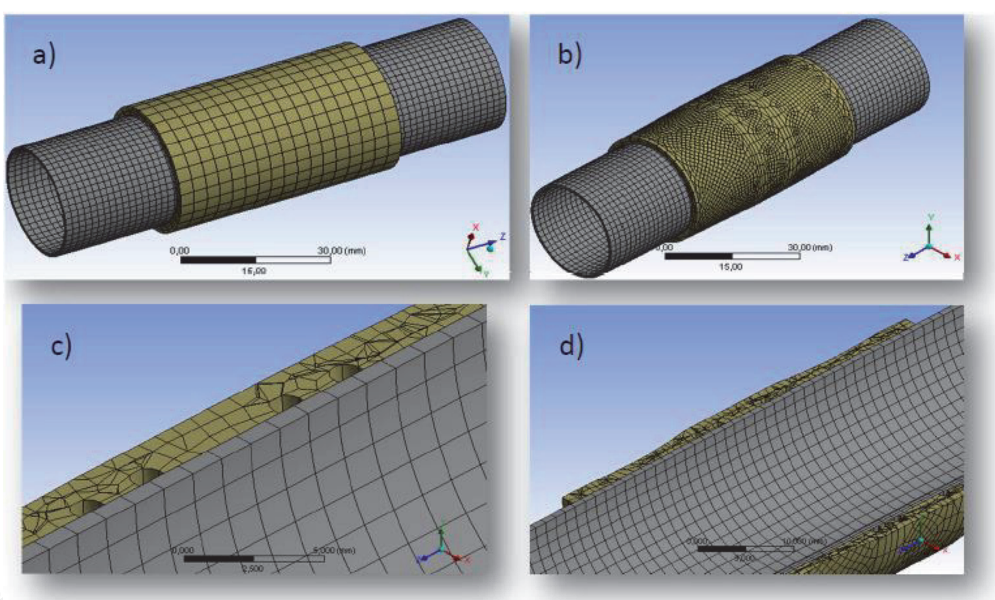

Figure 7.
Finite element model of swaged circle fitting design; a) flat; b) curve “a”; c) curved and fluted “B”; d) curved, ribbed and wavy “C” [13].

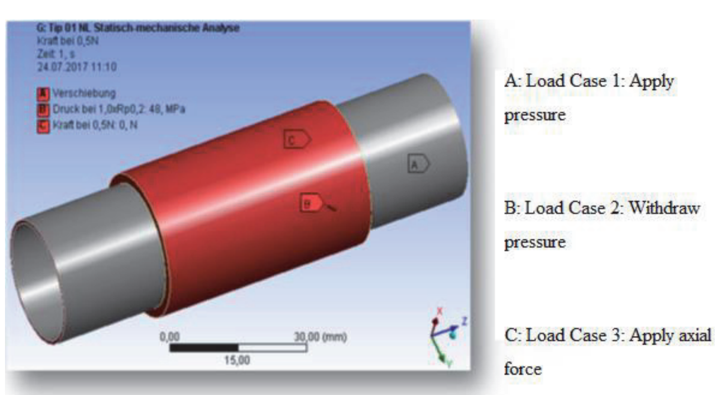

Figure 8.
Applied load cases (LC: Load case) [13].

deformation by applying pressure, it comes out under axial load very easily. Plastic deflection corresponds to approximately 12% of the total deflection. The pressure deformation in the inner pipe is very low.

In Model "A" in **Figure 10**; since plastic deformation is lagging behind when the small curved flat swaging circle fitting is released after being subjected to elastic–plastic deformation by applying pressure, it is now difficult to comes out under axial load. Plastic deflection corresponds to approximately 39% of the total deflection. Plastic deformation shows density in two places and is not homogeneous.

In Model "B" in **Figure 11**; since plastic deformation is lagging behind when the small curved flat swaging circle fitting with internal groove for sealing is released after being subjected to elastic–plastic deformation by applying pressure, it is now

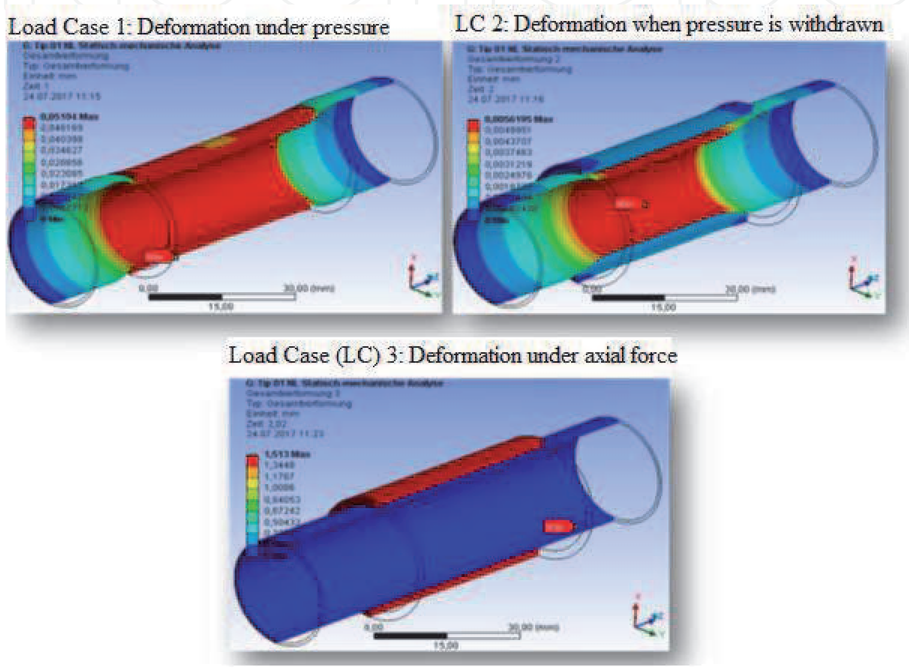

Figure 9.
Elastic–plastic deformations as flat fitting model FEM solution results [13].

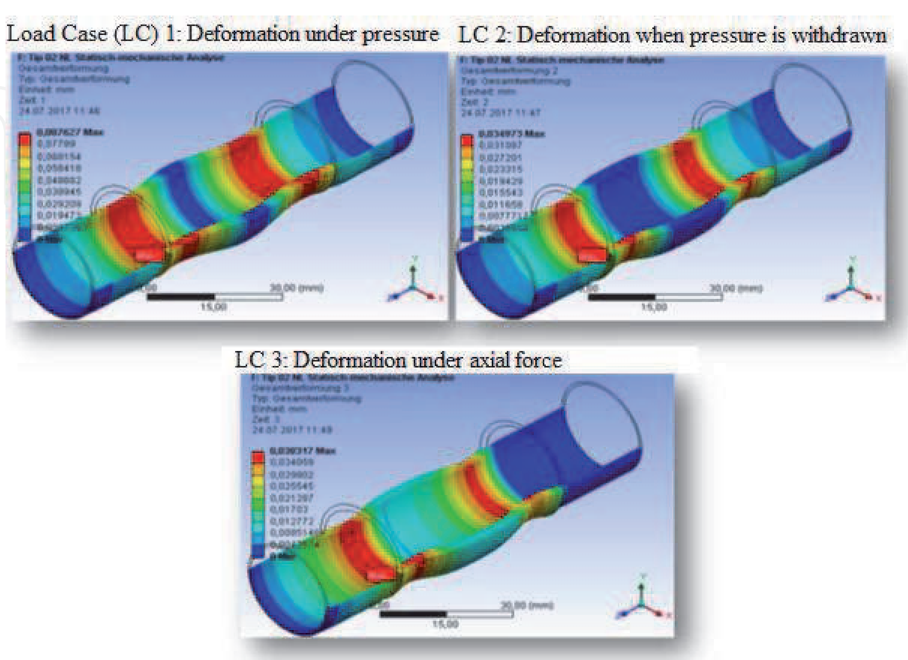

Figure 10.
Elastic–plastic deformations as model "a" FEM solution results [13].

difficult to comes out under axial load. Plastic deflection corresponds to approximately 17% of the total deflection. Plastic deflection distribution is more homogeneous than Model "A" but has a lower percentage.

In Model "C" in **Figure 12**; since plastic deformation is lagging behind when the small curved, axially wavy flat swaging circle fitting with internal groove for sealing is released after being subjected to elastic–plastic deformation by applying pressure, it is now difficult to comes out under axial load. Plastic deflection corresponds to approximately 78% of the total deflection. In this model, plastic deflection is both high and in the most homogeneous state. The deflection in the connected pipes is

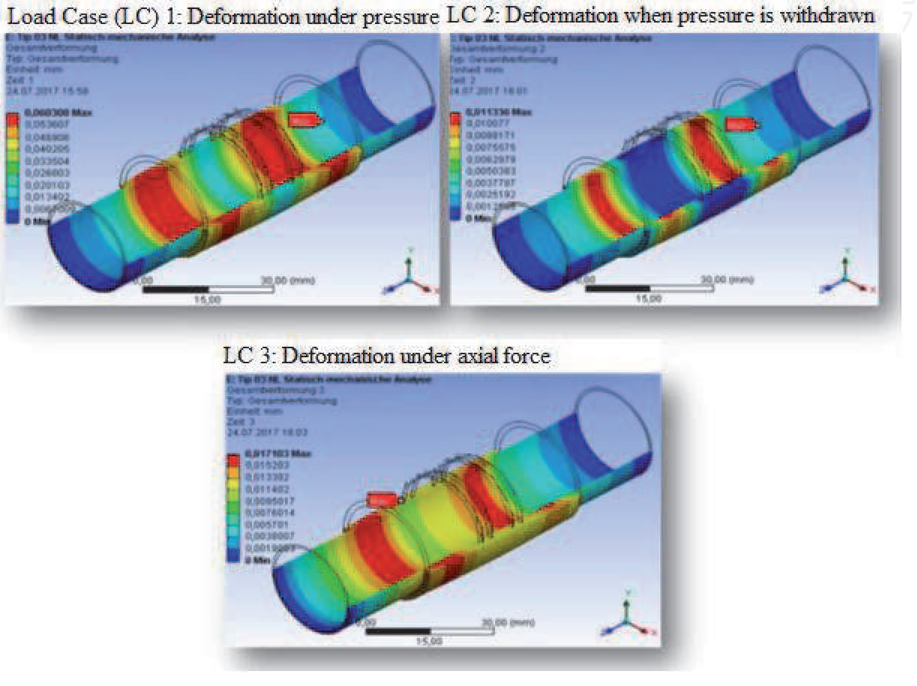

Figure 11.
Elastic–plastic deformations as model "B" FEM solution results [13].

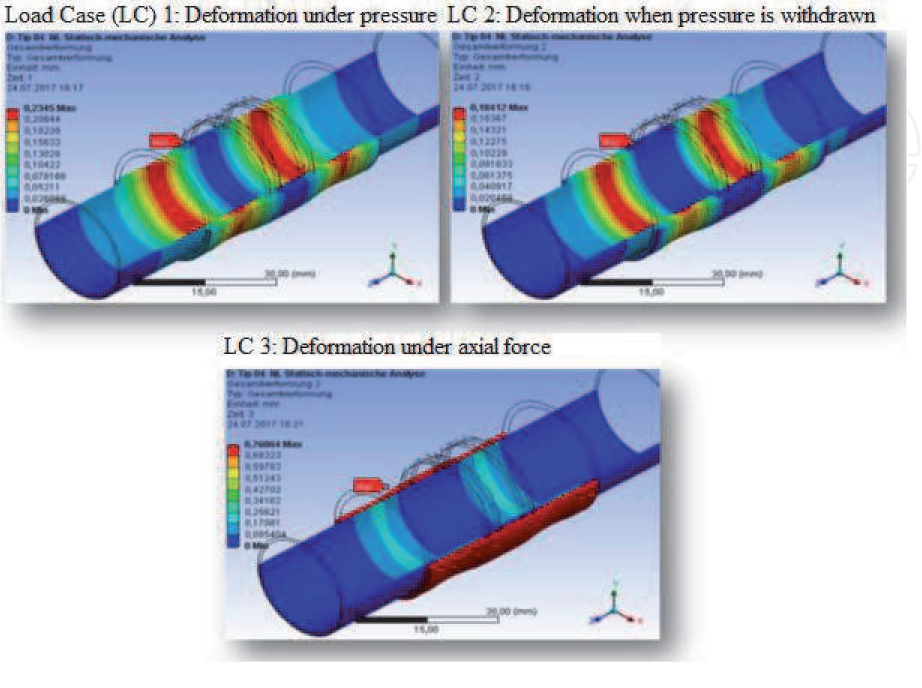

Figure 12.
Elastic–plastic deformations as model "C" FEM solution results [13].

within the elastic limits. It is possible to say that this connection showed a very good solution in terms of both sealing and strength

4. Conclusion

To conclude, in this study, it has been determined that the effect of the swaging circle fitting design on the tightened fittings has a great effect on the swaging force besides the parameters such as material and mechanical properties, use environment, swaging method, swaging circle fitting material, and that the most and homogeneous swaging occurs in the Model type "C" (curved, grooved and wavy) clamping fitting design [13].

Although it is possible to combine different materials and combine two different geometries with different methods, it has been shown in this study that combinations should be modeled and analyzed with advanced engineering since they are exposed to thermal and mechanical loads in terms of usage environments and has high requirements such as sealing [13].

Acknowledgements

I would like to thank my friend Osman Akgun, doctorate student at Gazi University for supporting to this study.

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