

Finite element analysis of reinforcement for gas insulated switchgear

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Abstract. Considering the burgeoning requirement for reinforcing gas-insulated metal-enclosed switchgear, a three-dimensional elastic-plastic finite element model was established to examine the stress distribution before and after reinforcement. The results showed that, under an internal pressure of 3.8 MPa, the maximum stress of the defective sample surpassed the yield strength of the material, leading to its destruction. On the other hand, the maximum stress value of the reinforced sample, with a gel and a reinforcing plate, decreased to 145 MPa and was lower than the yield strength of the material. Moreover, the results of the hydrostatic test further demonstrated that the gel was effective in reducing the stress concentration at the defect within a certain range. In particular, the results indicated that the gel was capable of decreasing the maximum stress value by 33 MPa, thereby safeguarding the structural integrity of the switchgear.

Keywords: Finite element, gas insulated switchgear, reinforcing gas-insulated metal-enclosed switchgear.

1. Introduction

Gas-insulated metal-enclosed switchgear (GIS) has been widely used in 110 kV and above power grids due to its advantages of compact structure, small footprint, high reliability and safety, and easy maintenance. A key component of GIS, the through-wall branch busbar, plays an important role in collecting, distributing, and transmitting electricity, in addition to connecting the indoor and outdoor busbars of GIS. However, if the shell is made out of aluminum alloy, corrosion may occur, leading to the possibility of air leakage, equipment power failure, and even perforation of the shell. With a large number of GIS having this through-wall busbar installation structure, most of them having been in service for around 10 years, this defect can become a significant threat to the security of the power grid if it is not addressed in a timely and effective manner. Consequently, it is essential to inspect these systems regularly and take necessary measures to prevent corrosion or repair the damaged structure, such as coating the aluminum alloy shell with suitable protective materials, to ensure the safety and reliability of the power grid.

With the advancement of composite materials, adhesive bonding repair technology has been widely employed in the repair of damaged structures. This technique not only enhances the strength of the structure, but also offers strong designability and a small weight gain [1-2]. In 2001, Meng Fanhao [3] et al. discovered that after adhesive repair of composite materials, the strength of the damaged parts could be restored to more than 90% of that of the intact mother plate. In recent years, numerical methods have been increasingly used in the repair design of composite materials. Li Gang [4] et al. studied the bonding structure of steel plate and aluminum alloy plate, which is commonly used in automobile body construction, and established a three-dimensional elastic-plastic finite element model. The results showed that when the thickness of the plate is the same, the adhesive layer stress on the aluminum alloy plate side is greater than the adhesive layer stress on the steel plate side. OUDADW [5] et al. used the three-dimensional nonlinear finite element method to investigate the

effects of gel properties and crack depth on the stress distribution at the crack tip. The results revealed that the bonding strength significantly reduced the stress at the crack tip.

Based on ANSYS finite element software, three-dimensional finite element models were developed for damaged and reinforced specimens respectively, in order to quantify the stress and strain distribution characteristics in the bonding and reinforcement area of the through-wall busbar shell of the gas-insulated composite electrical apparatus, and to validate the effectiveness of gel and reinforcing plate reinforcement by comparing with the measured results of the hydraulics tests.

2. Materials and Methods

2.1 Pressure test.

The GJSJ-300 pipe fitting press test machine was employed to conduct the experiment. The specifications of the pipe fitting were 320 millimeters in outer diameter, 300 millimeters in inner diameter, 500 millimeters in length and 16 millimeters in flange thickness. The material of the pipe was 6063 aluminum alloy. The damaged area of the defective sample had a rectangular structure; its defect size was 5 centimeters by 5 centimeters and its deepest surface size measured 9 millimeters, located in the middle. The reinforcing sample (which contained defects on the pipe) had a reinforcing plate measuring 10 centimeters by 10 centimeters by 6 millimeters, and the material used was 304 stainless steel. Prior to the reinforcement repair, the outer surface of the GIS pipe shell was polished, and then glue was used to fill the gap between the reinforcement plate and the pipe wall. Figure 1 and 2 depict the schematic diagram of the conformation member and the reinforcing member respectively. Finally, Table 1 outlines the mechanical properties of the aluminum alloy, gel, and stainless steel materials.

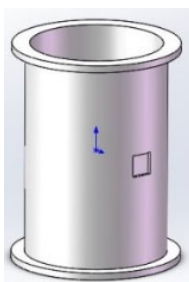
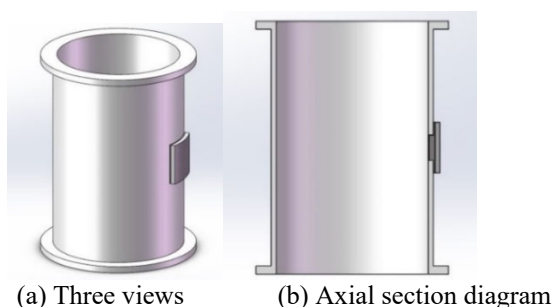


Figure 1. Schematic diagram of GIS pipeline defective components



(c) Radial section diagram

Figure 2. Schematic diagram of GIS pipeline reinforcement components

Table 1. Material and mechanical properties

Material	Poisson's ratio	Yield strength (Mpa)	Tensile strength (Gpa)
Aluminum alloy	0.3	165	70
Gel	0.25	66.3	66.2
Stainless steel	0.27	276	20.9

2.2 Finite element model building.

According to the size of the geometrical model of the shell-reinforced structure, the geometrical representation was established, and a non-uniform finite element mesh was created. Taking into account both the accuracy and efficiency of the computation, the mesh division at the notch, reinforcement area, and adjacent areas was densified; in contrast, the mesh at regions far from the weld was sparse, as pictured in Figure 3.

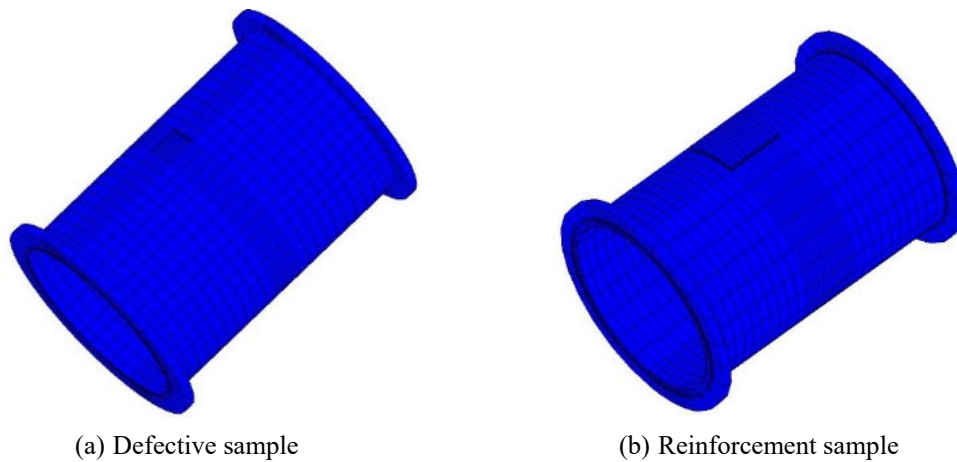


Figure 3. Geometric model meshing

3. Results and discussion

Firstly, the experiment was conducted on a pipe with defects of 5 cm x 5 cm and the deepest surface defect of 9 mm. Upon applying pressure at 3.8 MPa, the pipeline was damaged, as depicted in Figure 4a; a 1 cm wafer flew out, as depicted in Figure 4b and c. Subsequently, using gel reinforcement, a reinforcing plate of 10 cm x 10 cm was employed. Following the reinforcement, the pressure test remained intact at 7 MPa. When the pressure was further increased, the test was discontinued due to the failure of the gasket, as shown in Figure 4d and e.

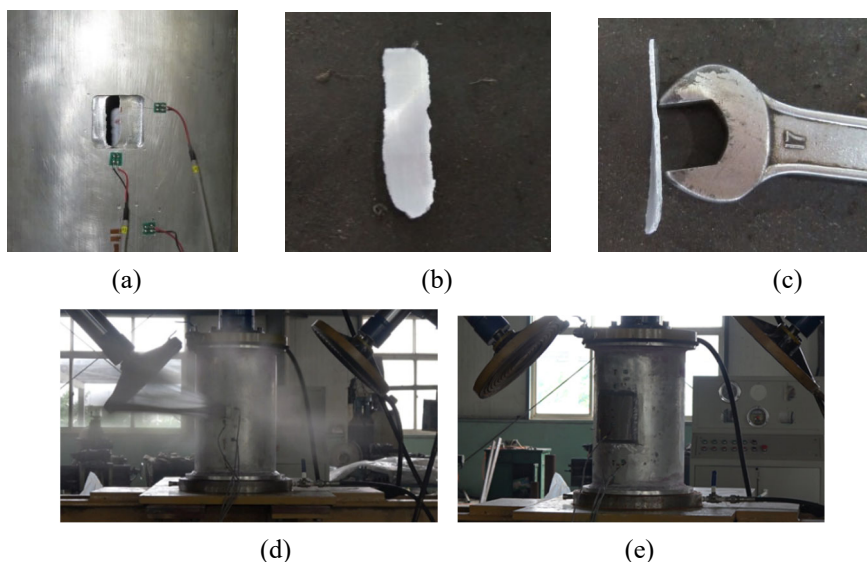


Figure 4. Test process diagram of GIS pipeline defect components and reinforcement components

Figure 5 illustrates the stress distribution contour of the defective pipeline member under an internal pressure of 3.8 MPa. As evidenced by Figure 5a, transverse stress concentration is evident near the defect, resulting in tensile stresses with a maximum magnitude of 160 MPa, approaching the material's yield strength. Similarly, Figure 5b reveals that longitudinal stress at the defect is 607 MPa, substantially exceeding the yield strength. Finally, Figure 5d shows equivalent stresses at the defect to be 179 MPa, which surpasses the material's yield capacity and validates experimental test results of damage to the pipeline.

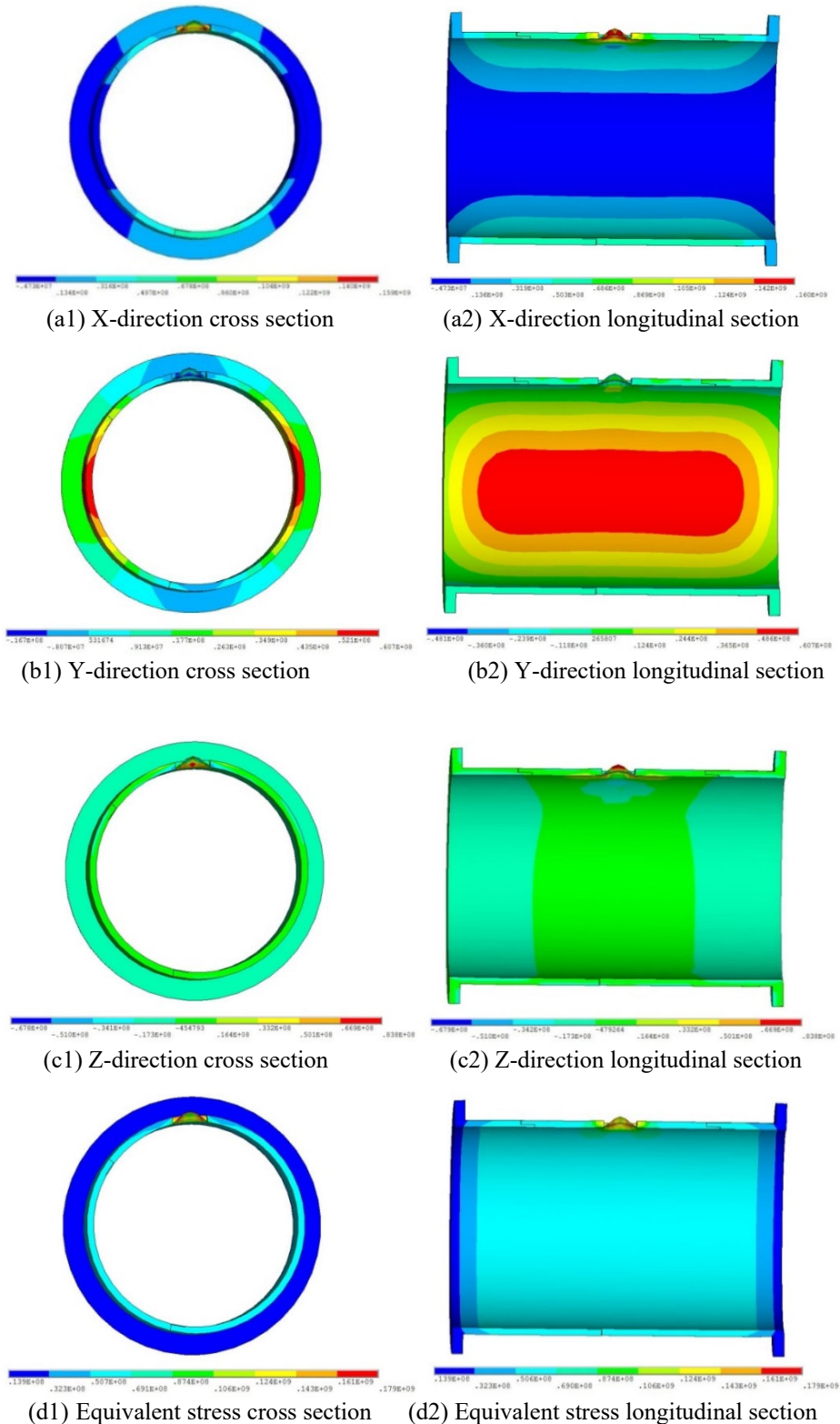


Figure 5. Stress distribution contour of defective sample

Figure 6 and Figure 7 illustrate the stress distribution contours of the pipeline reinforcement member when the internal pressure is 3.8 MPa. It can be seen from Figure 6a and 7a that for transverse stress, there is an area of concentrated tension near the notch, with a maximum value of 146 MPa, which is less than the yield strength of the material. For gel, the stress is minimal, with a maximum value of only 3.56 MPa, which is far lower than its yield strength. Furthermore, it can be observed from Figure 6d and 7d that for equivalent stress, the stress distribution is relatively uniform, with the stress value at the defect being 145 MPa. For gel, the stress is also more evenly distributed, with a maximum value of only 13.3 MPa.

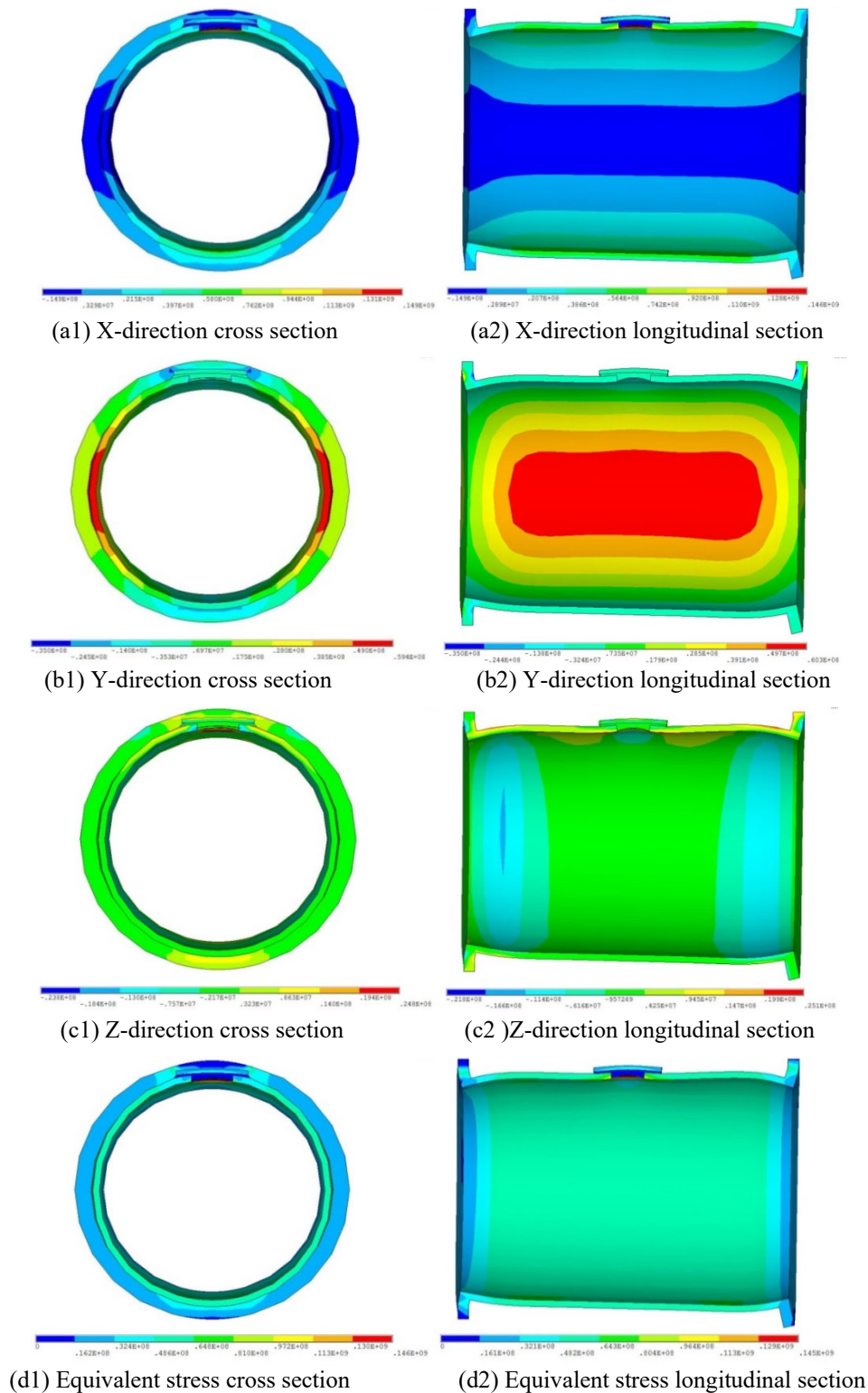


Figure 6. Stress distribution contour of reinforcement sample

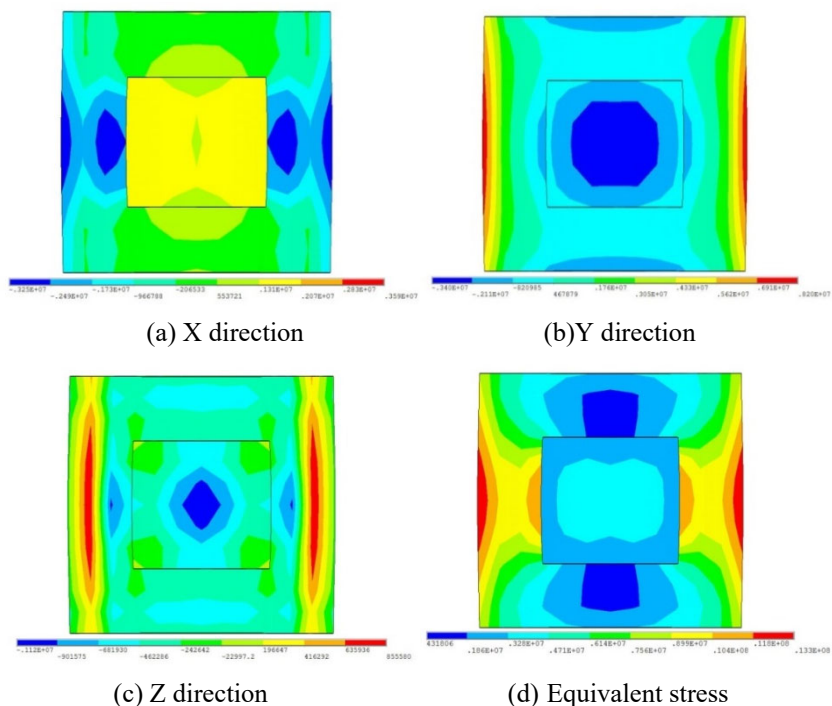


Figure 7. Contour of local stress distribution of gel of reinforcing sample

4. Conclusion

(1) When the pressure of the defective sample is 3.8 MPa, the maximum equivalent stress on the defective space of the defective sample is 179 MPa, which surpasses the yield strength, and thus, the sample suffers damage. For the reinforced sample under the same pressure of 3.8 MPa, the maximum equivalent stress proves to be 145 MPa, which is lower than its yield strength.

(2) The stress of the reinforced sample is lower than its yield strength, thereby fulfilling the practical demands of engineering, which may give assistance to ensure the safety and reliability of the power grid.

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