Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(5) (2020) 277-280
DOI: 10.22060/mej.2019.14646.5905

Modeling the Onset and Growth of Damage in Composite Cylinders under Lateral Pressure Loading Between Parallel Plates

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ABSTRACT: The present study examines the experimental and numerical investigations of the behavior and initiation and the development of the filament wound glass fiber/polyester composite cylinders under the loading of the lateral pressure between the parallel rigid plates. According to ASTM D2412-02 standard, the samples were organized between the parallel rigid plates under the pressured loading. In addition to conducting experimental tests, numerical simulation was performed using ABAQUS commercial software. In order to take into account the effects of the initiation and the development of damage, the 3D Hashin damage model has been utilized. To apply 3D Hashin damage model, a UMAT subroutine coding procedure was conducted using the Fortran 77 program. Using micro mechanical relations concerning the layers, the definition of mechanical properties and the fracture strength of the composite cylinder were separately obtained based on measuring fiber and resin properties and the relative standard. During the whole tests, experimental observations, including the level of failure due to loading and the cause of the occurrence of different mechanisms of damage, have been discussed. Comparison of the results of the experimental tests with the result of numerical simulation has an appropriate agreement with each other.

Review History:

Received: 6/1/2018
Revised: 9/28/2018
Accepted: 11/10/2018
Available Online: 2/4/2019

Keywords:

Composite cylinder
Damage onset
3D Hashin criteria
UMAT subroutine

1. INTRODUCTION

Glass-reinforced polymeric cylinders are used in a variety of industries, such as aerospace, oil and gas transmission, water transmission and chemical industries. The progress made in the manufacture of stranded cylinders has increased the interest in using them in fiber reinforced cylindrical composite structures.

In this paper, the aim of studying the nonlinear behavior of the structure and how to initiate and grow the mechanism of damage caused during loading in composite cylinders of a thread adjacent to the adjacent pressure load between the rigid panels and introducing a numerical modeling with finite element method To predict the nonlinear behavior of this type of structure with respect to the effects of damage in the form of 3D simulation.

2. EXPERIMENTAL STUDY

Samples of cylinders were made from a cylinder made by a discrete strand. The samples are 10 cm long and 20 cm in diameter. Materials used in the manufacture of composite cylindrical specimens, including polyester resin and glass fiber.

This resin is a type of isophthalic resin. The fiber used is of type E glass and is used as a direct roving. During the construction of the cylinder in this study, Mandrel's rotational velocity and carrier travel velocity were adjusted so that the mandrel surface was completely covered by the carrier and twist of the fibers once.

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Strings with a fiber angle of ±75. In the next step, the cylindrical screw-threaded cylinder, which is located in the vicinity of the electric torch, is rotated in a temperature range of 80-100°C for more than 120 minutes, until the baking process is complete and symmetric in the entire cylinder will be done. In Fig. 1, a cylindrical sample is observed.

2-1. Test of pressure between two parallel rigid plates

In order to conduct a pressure test between two parallel rigid plates, the test conditions were determined according to ASTM D2412-02 standard. In Fig. 2, the device is shown after the installation of rigid plates. It is worth noting that the size of the sample tested is chosen so that the composite cylinders examined are short tubes [1].

Fig. 1. Cylindrical sample

Fig. 2. Geometry and dimensions of the stretch test sample

3. NUMERICAL STUDY

In this paper, damage mechanics have been used to model the effects of damage in composite cylinders. For this purpose, the 3-D Hashin damage criterion has been used.

In order to simulate this in terms of the effect of damage in the 3D analysis, the implicit solution method should be written under the UMAT subroutine. As a result, the UMAT subroutine was written in Fortran 77, the format defined for Abacus software.

3-1. Hashin 3D criteria

Three-dimensional Hashin criteria was used to model the onset and growth of damage. Given the fact that the Hashin criterion for a unidirectional lamina is extracted, a filament wound composite cylinders is modeled with a multi-layered composite cylinder so each layer considered as a unidirectional composite layer. According to the 3D Hashin criteria, four different types of damage, i.e., tensile fiber failure, compressive fiber failure, tensile matrix failure, and compressive matrix failure were all considered. In the following, failure modes included in 3D Hashin criteria are introduced with the assumption that the shear strength longitudinal and transverse are equal [2].

1. Tensile fiber failure for $\sigma_{11} \geq 0$:

$$\left(\frac{\sigma_{11}}{X_T}\right)^2 + \frac{\sigma_{12}^2 + \sigma_{13}^2}{S^2} = 1 \tag{1}$$

$$\frac{\sigma_{11}}{X_T} = 1 \tag{2}$$

The value of each Eqs. (1) and (2) has a larger, which is taken into account in the calculation of the parameter of the damage in the tensile fiber failure.

2. Compressive fiber failure for $\sigma_{11} < 0$:

$$\frac{\sigma_{11}}{X_C} = 1 \tag{3}$$

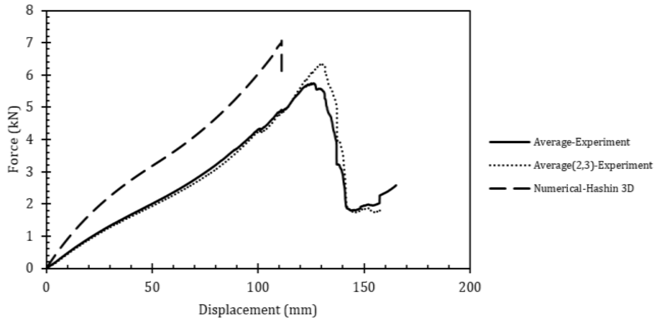

Fig. 3. Load-displacement diagram resulting from numerical simulation and average experimental results of cylindrical samples

3. Tensile matrix failure for $\sigma_{22} + \sigma_{33} \geq 0$:

$$\left(\frac{\sigma_{22} + \sigma_{33}}{Y_T}\right)^2 + \frac{\sigma_{23}^2 - \sigma_{22}\sigma_{33}}{S^2} + \frac{\sigma_{12}^2 - \sigma_{13}^2}{S^2} = 1 \tag{4}$$

4. Compressive matrix failure for $\sigma_{22} + \sigma_{33} < 0$:

$$\left[\left(\frac{Y_C}{2S}\right)^2 - 1\right]\left(\frac{\sigma_{22} + \sigma_{33}}{Y_C}\right) + \frac{(\sigma_{22} + \sigma_{33})^2}{4S^2} + \frac{\sigma_{23}^2 - \sigma_{22}\sigma_{33}}{S^2} + \frac{\sigma_{12}^2 - \sigma_{13}^2}{S^2} = 1 \tag{5}$$

4. RESULTS AND DISCUSSION

After placing the cylinder sample between two parallel rigid plates and applying pressure from the side of the upper plate, the structure deformation plate begins to come down. The cylinders are deformed during the pressure downward and perpendicular to the rigid plate gradually as a function of displacement of the plate. In addition to this kind of deformation, the cylinder is also deformed along the loading plate. As the plate's displacement increases, this deformation will be clearly visible. Also, numerical simulations for composite cylindrical samples are modeled under pressure conditions between two parallel rigid plates. The barrel-displacement diagram of the cylinder, which indicates the behavior of the composite cylindrical structure, has been investigated.

In Fig. 3, load-displacement diagrams derived from numerical simulation and average experimental results are presented.

As shown in Fig. 3, the numerical simulation behavior of the diagram is in good agreement with experimental results. This conclusion suggests that the process of simulation and selection of the criterion of damage and how it is defined is appropriate.

5. CONCLUSIONS

In this research, the behavior of the filament wound glass fiber/polyester composite cylinders under the loading of the lateral pressure between the parallel rigid plates. Subsequent numerical modeling with finite element method was proposed to predict the nonlinear behavior of this type with respect to the effects of damage in the form of 3D simulation. Considering the results of both numerical and experimental methods, it is clear that simulation is a suitable method for studying composite cylindrical behavior. The error from the numerical method was less than 23%. Due to the friction that occurs during construction and the ideal assumptions that apply during loading and applying boundary conditions in numerical simulation is appropriate. As a result, the 3D Hashin benchmark model with relations related to the effect of damage parameters on the stiffness matrix can be considered as a suitable measure for predicting the behavior of the composite cylinders of the stringed string under the compressive loading conditions in static and quasi-static loading. Damage during loading from the inner surface of the cylinder begins, and as the amount of loading increases, the damage increases along the thickness from the inner surface to the outer surface of the cylinder. In the case of a composite cylinder under compressive loading between two rigid sheets, both the shape of the damage of the fiber in the stretching and the fibers are effective in the pressure of the cylinder to reach the failure force.

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