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Research Article

Ultimate Strength of Pit Corrosion Damnification on Pressure-Resistant Shells of Underwater Glider

Shaojuan Su, Tianlin Wang, Chunbo Zhen, and Fan Zhang

Naval Architecture and Ocean Engineering College, Dalian Maritime University, Dalian, Liaoning, China

Correspondence should be addressed to Shaojuan Su; 32248522@qq.com

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The ultimate strength of the pressure-resistant shells is degraded due to corrosion pit on the surface of the shells. The underwater glider is prone to pit corrosion damage after working in the water for a long time. This study is aimed at development of an assessing formula for ultimate strength of pressure-resistant shells with pit damage. Firstly, a parameterized geometry model of the pit is determined under the assumption that the pits are elliptical. Secondly, a finite element numerical simulation model is established and the numerical simulation results are analyzed to find that the effect of pit damage on the pressure-resistant shell is obvious. Thirdly, the influences of some parameters (relative length, relative width, and relative depth) of pit on the ultimate strength are studied. The regular curve of the influence of geometric parameters on ultimate strength is drawn. Lastly, the ultimate strength assessment formula of pressure-resistant shells was obtained from the data by nonlinear FEM based on the regression function of multiple nonlinear regression analysis by nonlinear regression analysis function regress which can provide the foundation to assess the ultimate strength of damaged pressure-resistant shells.

1. Introduction

Due to the particularity of the underwater glider, the rest of the time will be in seawater except for charging or maintenance. Therefore, its pressure-resistant shell will face a strong external environmental damage. In general, pit corrosion damage is the most common type to pressure-resistant shell. There are many factors that cause pit corrosion damage. For example, the destruction of seawater and marine life will cause electrochemical reactions of glider pressure-resistant shells and direct external damage of pressure-resistant shells in the marine environment, which will lead to pit corrosion damage. Although we will apply paint and other anticorrosion measures to protect the pressure-resistant shell, it is inevitable that the glider pressure-resistant shell working in a very harsh environment is destroyed. The pit damage causes the thickness of the pressure-resistant shell to become thinner, which has great safety risks and has serious impact on the safety of the entire underwater glider structure. The evaluation of the ultimate strength of the pressure-resistant shell with pit corrosion damage is the basis of the safety assessment for the overall structure.

Because of the complexity of geometrical nonlinearity and constitutive relations, it is difficult to find an exact solution by analytical method. For the calculation of the ultimate strength of pitting damage, a more representative study is Sadovsky and Drdacky [1]. Using statistical data from experimental studies, the critical buckling load of locally corroded slabs is obtained by statistical methods. Dunbar et al. combined finite element simulation analysis and experimental methods to discuss the effect of corrosion on the stability of the square plate [2]. Nakai et al. conducted a series of experiments and finite element tests on the ultimate strength of bulk carriers with local pitting corrosion; the ultimate strength is related to pitting distribution, pitting location, and plate thickness [3–5]. Duo Ok et al. calculated the knot with 256 nonlinear finite elements for two cases where there is corrosion in the edge region. An empirical formula for predicting the ultimate strength of locally corroded nonreinforced plates is obtained [6, 7]. Yan Zhang et al. got the ultimate strength calculation of pitted stiffened plates under uniaxial compression by the data analysis from lots of nonlinear finite element analyses [8]. Ahmad Rahbar-Ranji et al. employed a series of nonlinear finite element method

Table 1: 7075 performance parameters of aviation aluminum.

Density (kg/m^3)	Young's Modulus (Mpa)	Poisson's ratio	Conditional yield strength (Mpa)	Allowable stress (Mpa)
2800	717000	0.33	505	328

Table 2: Geometrical parameters of pressure shell and corrosion pit.

a	R	b	L	h	t
Pit long axis	Pit center circle radius	Pit short axis	Pit center busbar length	Depth of pit	Shell thickness

for ultimate strength analysis of stiffened plates with pitting corrosion [9].

In this paper, the ultimate strength of the pressure-resistant shell with pit corrosion damage is calculated by numerical simulation technology. It is assumed that the pits are elliptical and the effects of relative length, relative width, and relative depth of pit on the ultimate strength of the pressure-resistant shell are studied. Finally, the calculation results are regressed and analyzed by Matlab software, and the empirical formula of the ultimate strength of the pressure-resistant shell with pit corrosion damage is obtained.

2. Geometric Parametric Model

In general, there are local corrosion damage and total corrosion damage to the glider's pressure-resistant shell. And the local corrosion to the pressure shell is far greater more complex than the other corrosions because the local corrosion has many sources of influence on the pressure shell, and it is difficult to determine it. In this paper, pits corrosion is considered as the object of local corrosion.

In terms of pit corrosion, the length, width, and depth of the corrosion pit are called damage parameters. Solidworks is used to model the pressure-resistant shells with different defect parameters, and then it is imported into finite element analysis software to perform parametric analysis to the ultimate strength of pressure-resistant shells with corrosion pits. The remaining ultimate strength of the shell is solved. Analyze all the result data obtained and plot the influence of different defect levels on the ultimate strength of the pressure shell and analyze the regular.

2.1. Assumptions . In order to better ensure the quality and accuracy of meshing, we make the following assumptions about the pressure-resistant shell of the glider:

(1) The material used in the aluminum alloy is an ideal plastic unit and is isotropic.

(2) The outline of the corrosion pit is a regular ellipse.

2.2. Determining the Geometric Model. For the finite element analysis of the pressure-resistant shell with corrosion pits after the assumption is simplified, the boundary conditions and the load application method are set, and the accurate calculation is obtained and the accurate result is obtained.

2.2.1. Material Parameters. The material used in the pressure shell is 7075 aluminum alloy. The parameters are as shown in Table 1.

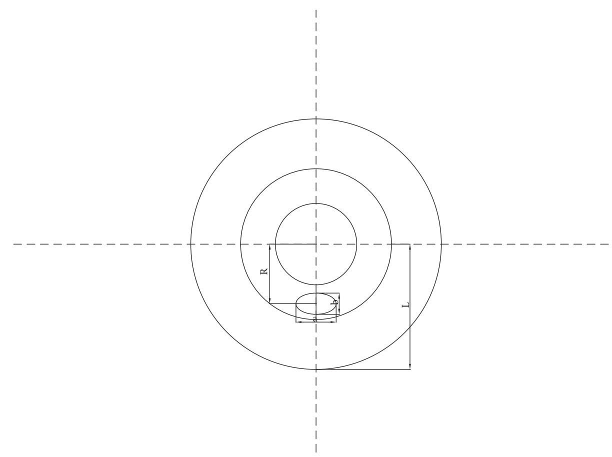

Figure 1: Corrosion pit.

Table 3: Dimensionless table of geometric parameters and ultimate strength.

$\alpha = a/2\pi R$	$\beta = b/L$	$\gamma = h/t$	$\lambda = \sigma_I/\sigma_{II}$
Relative length	Relative width	Relative depth	Ultimate strength factor

2.2.2. Geometric Model. The ellipsoidal shape pit is used for parametric analysis. The geometric data of the pressure-resistant shell with corrosion pit is shown in Figures 1 and 2, in which the corrosion pit is located between the 2nd and 3rd reinforcement rings of the pressure-resistant shell.

To quantitatively describe corrosion pits, introduce the following parameters, shown in Table 2.

In order to make the nondimensionalization between the ultimate strength and the geometrical parameters of the pressure-resistant shell with corrosion pits, the definitions are made in Table 3.

Among them, σ_I is the residual ultimate strength of the pressure-resistant shell with corrosion pits, and σ_{II} is the ultimate strength of the pressure-resistant shell without corrosion.

2.2.3. Load Application and Determination Ultimate Strength. The working environment of the circular dish underwater glider is mainly for various sea areas, so the external load is mainly deep-water hydrostatic pressure and the dynamic pressure and static pressure produced by the current on the

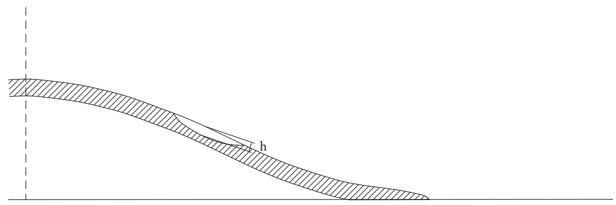

Figure 2: Corrosion pit pressure shell profile.

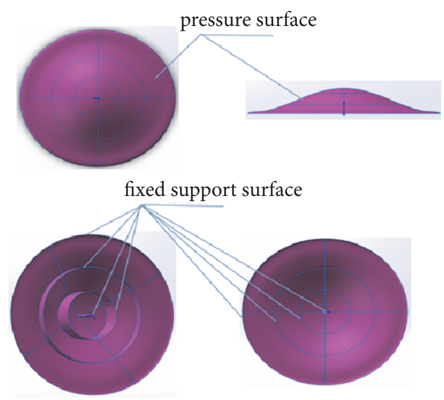

Figure 3: Sketch of boundary conditions.

pressure-resistant shell is negligible. Therefore, taking the edge of the pressure shell and the three reinforcement ring contact surfaces as a fixed support, the pressure surface is the entire outer surface of the pressure shell, as shown in Figure 3, and the pit surface also acts as a pressure surface to determine the mechanical properties of the pressure shell.

In the process of loading the load, the time displacement curve of the pressure-resistant shell can be obtained through calculation, and the load value corresponding to the abrupt change position of the curve is the ultimate strength of the pressure-resistant shell.

3. Finite Element Model

3.1. Establish Finite Element Model. Taking the corrosion pit pressure-resistant shell with the parameters $a = 106.1mm$, $b = 32.8mm$, and $h = 0.9mm$ as an example, the ultimate strength is calculated. The three-dimensional model of the pressure-resistant shell is shown in Figure 4.

3.2. Model Grid Division and Solution Settings. When meshing the model, in order to get more accurate calculation results, we encrypt the meshes of the cells near the damaged pits by creating a new coordinate system in the center of the ellipse and inserting the influence ball. The refined mesh size is set to 2.5 mm, and for other areas far away from the damaged pits, the mesh size is 10 mm. The finite element model is shown in Figure 5.

When solving the ultimate strength of pressure-resistant shells with damaged pits, nonlinear static analysis is adopted to solve the ultimate strength of the model, and arc length method is introduced to control convergence.

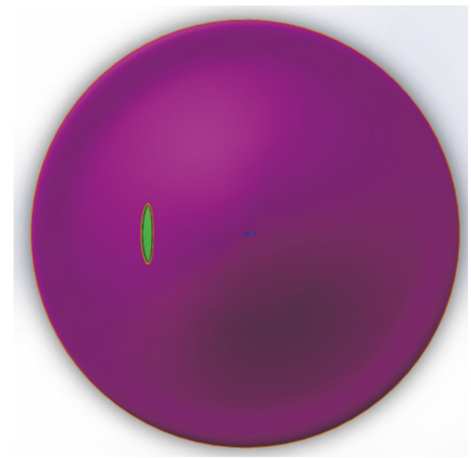

Figure 4: Pressure hull model with corrosion pits.

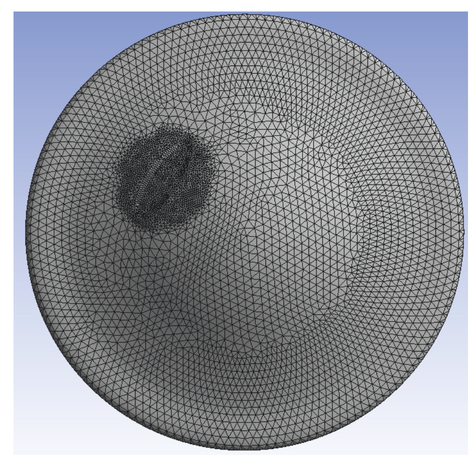

Figure 5: Meshing diagram of pressure hull with corrosion pits.

3.3. Result Analysis. From the overall deformation nephogram obtained by finite element analysis, it is found that large deformation occurs at first in the area near the corrosion pit, which indicates that the influence of the corrosion pit on the pressure-resistant shell is obvious. The overall deformation nephogram is shown in Figure 6.

After further calculation and analysis, we found that the pressure-resistant shell with corrosion pits was obviously influenced by the position of the second reinforcing ring near the corrosion pits, which significantly reduced the ultimate strength. The deformation nephogram and time displacement curve of the shell are shown in Figure 7.

The hydrostatic pressure of 2 MPa is gradually applied to the outer surface of the shell for 20 seconds. From the time displacement curve in Figure 8, it can be found that the structure suddenly changes in 12.304 seconds; that is, the ultimate strength of the pressure-resistant shell is 1.2304 MPa at this time.

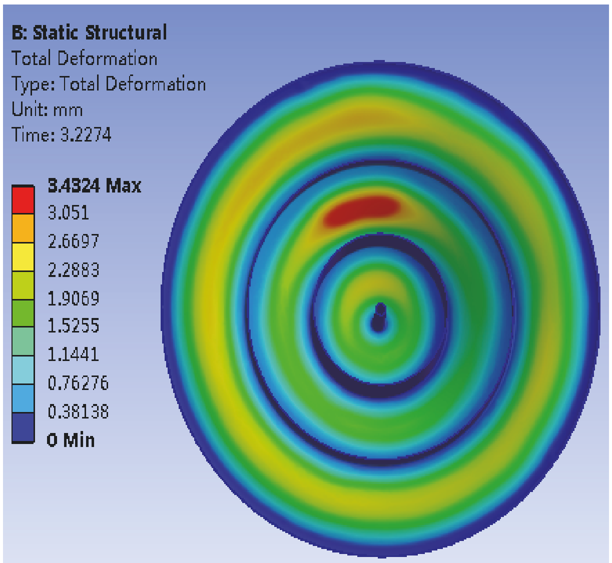

Figure 6: Overall deformation nephogram of pit corrosion resistant shell.

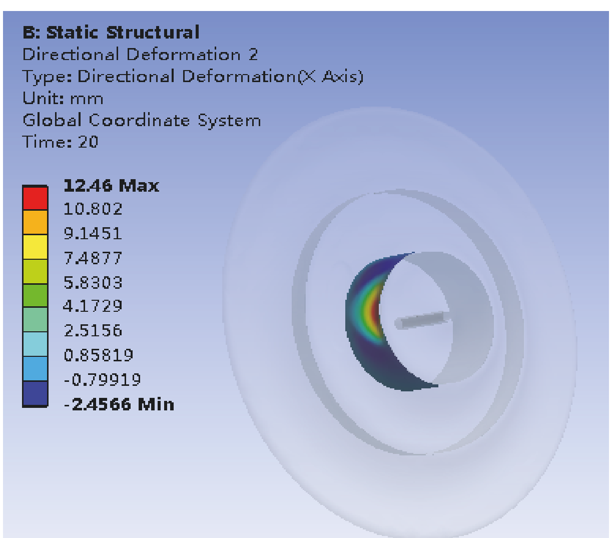

Figure 7: Deformation nephogram of the second ring region.

4. Parametric Analysis

Considering the actual use, the length direction shall not exceed half of the circumference of the water glider at the center of the pit, the width shall not exceed the edge of the glider, and the depth shall not exceed 0.75 times the thickness of the plate. So the range of relative length $\alpha \in [0, 0.5]$, the relative width $\beta \in [0, 1]$, and the relative depth $\gamma \in [0, 0.75]$. In order to obtain the influence of geometric parameters on ultimate strength of pressure hull, we discretize the parameters. Here α takes a value of 0.1, 0.2, 0.3, 0.4, 0.5, β takes a value of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, and γ takes a value of 0.15, 0.3, 0.45, 0.6, 0.75.

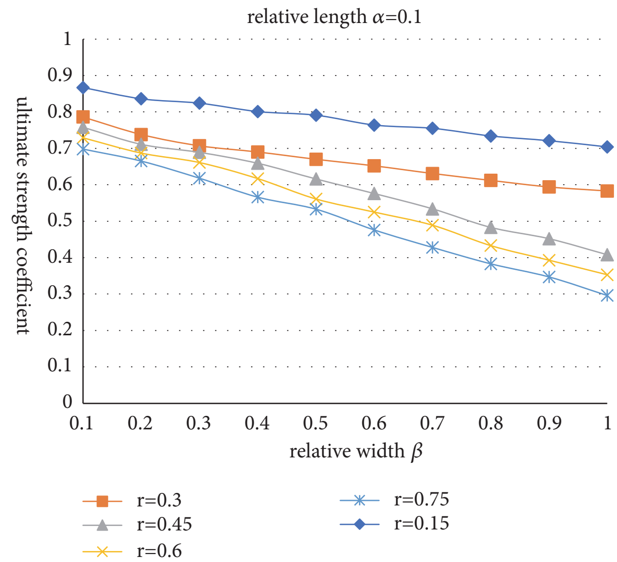

Figure 8: The graph of relative width on ultimate strength.

Table 4: Effect of relative width on ultimate strength coefficient.

α		0.1				
γ		0.15	0.30	0.45	0.60	0.75
β	0.1	0.867	0.786	0.758	0.729	0.698
	0.2	0.836	0.738	0.711	0.687	0.665
	0.3	0.824	0.707	0.689	0.661	0.618
	0.4	0.801	0.69	0.659	0.617	0.566
	0.5	0.791	0.67	0.616	0.561	0.533
	0.6	0.764	0.652	0.576	0.525	0.476
	0.7	0.755	0.631	0.534	0.489	0.428
	0.8	0.734	0.612	0.483	0.433	0.383
	0.9	0.721	0.594	0.452	0.393	0.347
	1.0	0.704	0.583	0.408	0.353	0.296

By means of second chapters, the ultimate strength of the pressure-resistant shells without pits is 1.6691MPa. The ultimate strength coefficient of the damaged shell is 1.2304/1.6691=0.737.

After finite element calculation, the calculation results of the ultimate strength coefficient of pressure-resistant shell with different dent parameters are summarized in Tables 4, 5, and 6. From these tables, it is found that the three parameters of the damaged pits have a direct impact on the ultimate strength of the pressure-resistant shell, and the specific influence rules are shown as follows.

4.1. Effects of Relative Width on Ultimate Strength. According to the calculation results of the ultimate strength of the pressure-resistant shell with the corrosion pit, the calculation results of the limit strength coefficients are summarized in Table 4 in which relative length $\alpha = 0.1$ and relative depth γ is 0.15, 0.3, 0.45, 0.6, 0.75

According to Table 4, draw a regular graph of the ultimate strength with relative width β, as shown in Figure 8.

Table 5: Effect of relative depth on ultimate strength.

β		0.3				
α		0.1	0.2	0.3	0.4	0.5
	0.15	0.874	0.868	0.857	0.845	0.823
	0.3	0.849	0.835	0.826	0.816	0.801
γ	0.45	0.838	0.829	0.817	0.803	0.791
	0.6	0.83	0.822	0.809	0.798	0.783
	0.75	0.828	0.818	0.805	0.795	0.779

Table 6: Effect of relative length alpha on the ultimate strength.

γ		0.3				
α		0.1	0.2	0.3	0.4	0.5
	0.1	0.876	0.872	0.867	0.861	0.856
	0.2	0.851	0.849	0.846	0.843	0.839
	0.3	0.834	0.831	0.828	0.825	0.819
	0.4	0.825	0.819	0.815	0.811	0.806
	0.5	0.817	0.809	0.803	0.797	0.788
β	0.6	0.791	0.788	0.785	0.780	0.766
	0.7	0.779	0.773	0.769	0.765	0.761
	0.8	0.769	0.764	0.758	0.753	0.747
	0.9	0.758	0.752	0.749	0.745	0.741
	1.0	0.755	0.748	0.743	0.738	0.730

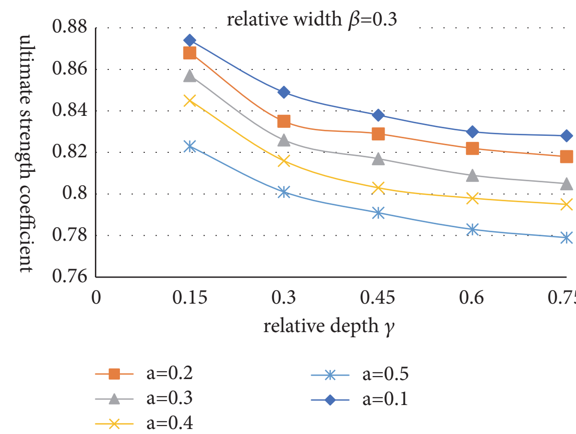

Figure 9: The graph of relative depth on ultimate strength.

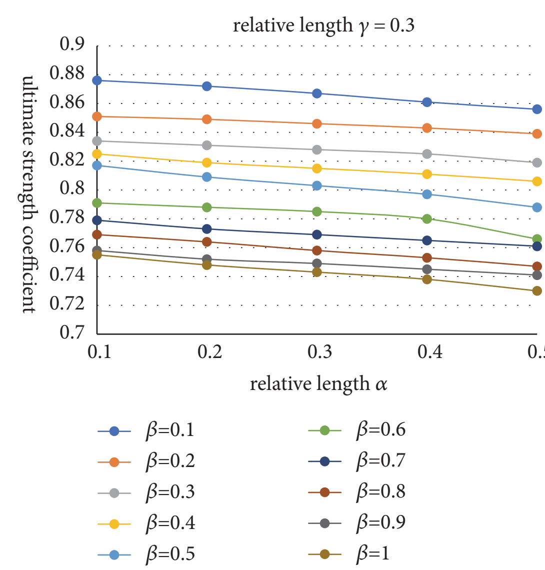

Figure 10: The graph of relative length on ultimate strength.

From Figure 8, the width of the damaged pit has a significant effect on the ultimate strength of the pressure-resistant shell, because, with the increase of the width of the pit, the strength of the inner ring 2 of the pressure-resistant shell is greatly affected, which directly leads to the reduction of the overall ultimate strength of the pressure-resistant shell. At the same time, it can also be found that the limit strength of the pressure-resistant shell varies linearly with the relative width of the corrosion pit. When the width of the corrosion pit increases, the limit strength of the pressure-resistant shell decreases significantly and increases with the relative depth γ. The reduction of ultimate strength of pressure-resistant shell is more significant.

4.2. Effect of Relative Depth on Ultimate Strength. According to the calculation results of the ultimate strength of the pressure-resistant shell with the corrosion pit, the calculation results of the limit strength coefficients are summarized in Table 5 in which relative width $\beta = 0.3$ and relative length α is 0.1, 0.2, 0.3, 0.4, 0.5

According to Table 5, draw a regular graph of the limit strength with relative depth γ, as shown in Figure 9.

From Figure 9, we can see that when the relative width β and relative length α of the damaged pit remain unchanged, the ultimate strength of the pressure-resistant shell decreases significantly with the increase of relative depth γ. At the same time, from the changing regular of the curve, it can be seen that in the first half of the relative depth γ gradually increasing, the limit strength of the pressure-resistant shell decreased sharply, and in the second half of the relative depth γ gradually increasing, the limit strength of the pressure-resistant shell gradually decreased. On the whole, with the increase of relative depth, the linear characteristics of the ultimate strength of the pressure-resistant shell are not strong, and it can be approximated as nonlinear.

4.3. Effect of Relative Length on Ultimate Strength. According to the calculation results of the ultimate strength of the pressure-resistant shell with the corrosion pit, the calculation results of the limit strength coefficients are summarized in Table 6 in which relative width $\gamma = 0.3$ and relative length β is 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0.

According to Table 6, a regular graph of the ultimate strength with the relative length α is drawn, as shown in Figure 10.

From Figure 10, it can be found that the ultimate strength of the pressure-resistant shell containing the damaged pit is approximately linear to the relative length α under different relative widths. When the corrosion pit width is certain,

Table 7: The optimal fitting results.

Geometric parameters	Fitting curve equation	Correlation coefficient
α	$y = 0.9062\gamma^3 + 1.7665\gamma^2 - 1.424\gamma - 0.33\beta + 1.1386$	0.9714
β	$y = -0.3852\gamma^3 + 0.6825\gamma^2 - 0.4263\gamma - 0.121\alpha + 0.9394$	0.9954
γ	$y = -0.0471\alpha - 0.1388\beta + 0.8866$	0.9920

the ultimate strength of the pressure-resistant shell gradually decreases with the relative length α. At the same time, when the relative width of the corrosion pit continues to increase, the residual ultimate strength of the pressure-resistant shell decreases not significantly with the increase of the relative length. To sum up, the effect of the corrosion pit length on the residual limit strength of the shell is minimal compared with the width and depth.

5. Formula on Ultimate Strength of Pressure-Resistant Shell with Corrosion Pit

The results of finite element analysis show that the relative length α, relative width β, and relative depth γ of the damaged pit have different degrees of influence on the ultimate strength of the glider's pressure-resistant shell, and the degree of influence varies with the changing trend of pit parameters. The finite element software is used to simulate the ultimate strength of the pressure-resistant shell damage. Although it is relatively scientific and perfect, the calculation process is quite complicated and time-consuming, and it can not be well applied to engineering practice. Therefore, it is very important to fit the empirical formula between the limit strength and the damage parameters in order to calculate the limit strength of the shell with the corrosion pit more easily and accurately.

5.1. Curve Formula Fitting between the Geometric Parameters. From Figures 8, 9 and 10, we can clearly find that the limit strength of the pressure-resistant shell damage has a clear linear relationship with the relative length α, a clear linear relationship with the relative width β, and an approximate nonlinear relationship with the relative depth γ relationship.

The above is only a qualitative analysis of the impact of the pit geometry parameters on the ultimate strength. In order to realize the simple and accurate prediction of the limit strength of the pressure-resistant shell pit in the same type of underwater glider, the geometrical parameters of the corresponding corrosion pit must be quantitatively analyzed. Matlab software is used to fit the curve formula between the finite element results and the geometric parameters of each corrosion pit. The curves and scattered points shown in Figures 11, 12, and 13 are obtained.

The optimal curve fitting equation is obtained by multiple fitting as shown in Table 7.

The fitting curve of single geometric parameters and pit limit strength coefficient can not comprehensively reflect the effect of limit strength coefficient and relative value of geometry parameter. However, it can reflect the influence of the geometric parameters of the single damage on the ultimate strength coefficient of the pressure-resistant shell. According

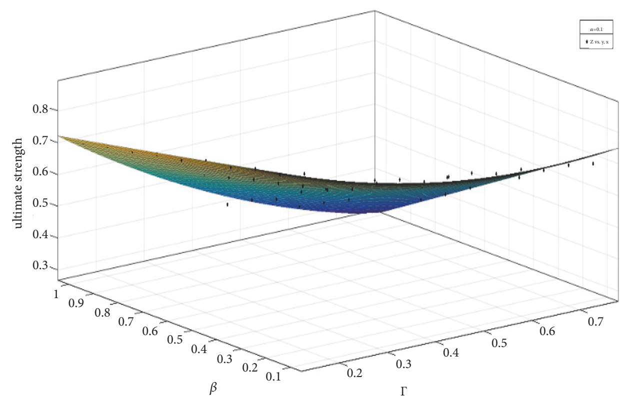

Figure 11: The formula fit graph of ultimate strength with β and γ.

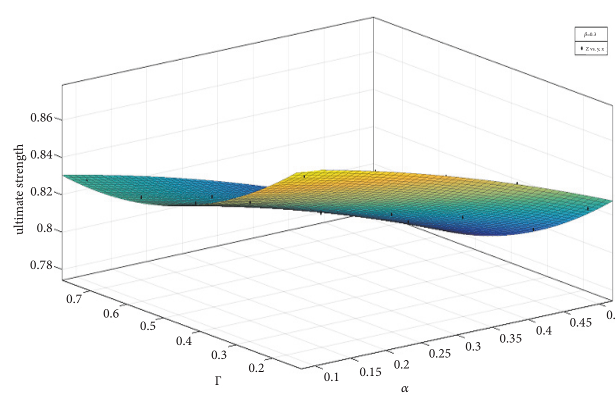

Figure 12: The formula fit graph of ultimate strength with α and γ.

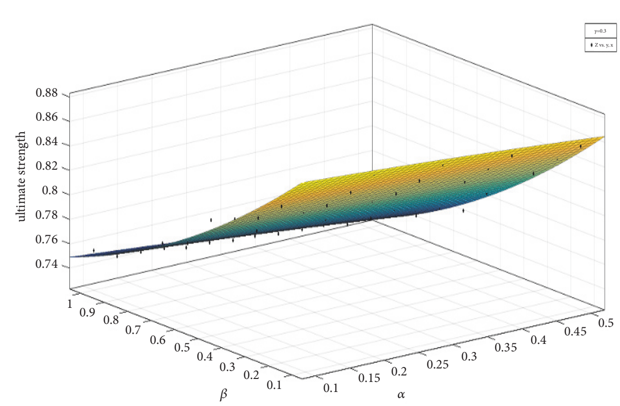

Figure 13: The formula fit graph of ultimate strength with α and β.

to Table 7, it can be seen that the limit strength coefficient of the pressure-resistant shell has a linear relationship with the pit-shaped geometric parameters α and β and a nonlinear relationship with γ.

5.2. Regression Analysis and Validity Verification. In order to analyze the relationship between the limit strength coefficient and the nonquantized geometrical parameters α, β, and γ, the multiple nonlinear regression analysis function in Matlab software is used to analyze the finite element calculation results of the ultimate strength of the pressure-resistant shell.

According to Table 7, the relationship between the nonquantized geometric parameters and the ultimate strength can be seen, and the relationship is drawn as

$$\mathrm{y} = A + B\alpha + C\beta + D\gamma + E\gamma^2 + F\gamma^3 \quad (1)$$

Combined with Tables 4, 5, and 6, regression analysis based on multivariate nonlinear regression analysis function regress is done.

According to Table 4, the vector is as follows. Similarly, the vectors of Tables 5 and 6 can be made.

α = [0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1]

β = [0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0]

γ = [0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.45 0.45 0.45 0.45 0.45 0.45 0.45 0.45 0.45 0.45 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75]

y = [0.867 0.836 0.824 0.801 0.791 0.764 0.755 0.734 0.721 0.704 0.786 0.738 0.707 0.69 0.67 0.652 0.631 0.612 0.594 0.583 0.758 0.711 0.689 0.659 0.616 0.576 0.534 0.483 0.452 0.408 0.729 0.687 0.661 0.617 0.561 0.525 0.489 0.433 0.393 0.353 0.698 0.665 0.618 0.566 0.533 0.476 0.428 0.383 0.347 0.296]

The 125-dimensional vectors of α, β, γ, and y can be got by combining Tables 4, 5, and 6. According to the multivariate nonlinear regression analysis function regress formula (2) is obtained.

The code in Matlab is as follows.

```
y = [ones(125, 1) x1′ x2′ x3′ (x3.^2)′ (x3.^3)′];
[b,bint,r,rint,stats]=regress(y,X);
```

where x1′ x2′ x3′ is α, β, γ.

$$y = -0.585\gamma^3 + 1.1959\gamma^2 - 1.003\gamma - 0.2743\beta - 0.0562\alpha + 1.0989 \quad (2)$$

After the regression analysis formula is obtained, its results need to be evaluated to determine its credibility. The correlation coefficient can be used as the basis for judging the results. The closer the correlation coefficient is to 1, the higher the credibility of the results of regression analysis. According to the calculation results, when the curve fitting equation is formula (2), the correlation coefficient R2 = 0.9753, and the result is closer to 1, so it has a higher credibility.

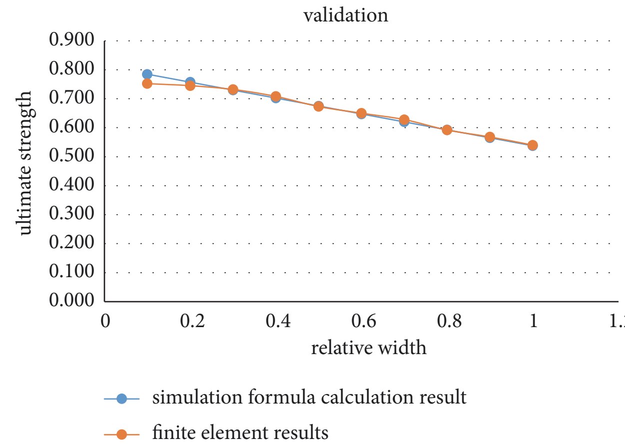

Figure 14: Comparison of the fitting formula and finite element results at different width.

The ultimate strength with $\alpha = 0.2$, $\gamma = 0.5$ corrosion pit is calculated using the finite element method at different width β.

At the same time, in order to verify the accuracy of the resulting regression formula (2), pick more points for analysis. The ultimate strength with different depth and different length are simulated to verify the accuracy of the regression formula, due to space reasons not listed in the paper. From Figure 14, we can find that the result of the fitting regression formula is very consistent with the finite element calculation result, which shows that the fitting regression formula is accurate.

6. Conclusion

Ultimate strength is calculated by finite element software in this paper. The effects of corrosion pit on the ultimate strength with different parameters (relative length α, relative width β, and relative depth γ) are studied qualitatively and quantitatively. The regression analysis is carried out by using the regress function in Matlab software and fitting formula on ultimate strength of pressure-resistant shell with pit is obtained. The analysis shows that the ultimate strength of the disc shell is obviously affected by the width and depth. However, the effect of pit length on the ultimate strength of the pressure-resistant shell is not obvious. At the same time, we can also know that the length and width of the pit have a linear relationship with the ultimate strength and a nonlinear relationship with the depth.

In this paper, the pit defects which have the most obvious influence on the pressure-resistant shell were analyzed. But only the effects of single pit damage on the ultimate strength are studied. The actual pit distribution is randomly distributed, and the size and shape are also uncertain. The situation is more complicated. Analysis has great limitations in the paper. But it also provides a research idea for the next study of pressure-resistant shell damage. In the next research, we can use the research ideas proposed in this paper to analyze the ultimate strength of the pressure-resistant shell with multiple pits to get the analysis regular and fit the empirical formula so as to simplify the damage analysis of the pressure-resistant shell in the future.

Data Availability

(1) The nondimensionalization calculation data used to support the findings of this study are included within the article. (2) The water glider pressure shell structure data used to support the findings of this study have not been made available because this product is currently under patent protection and has not been published yet. But the nondimensionalization calculation data is enough and does not affect the calculation results.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] Z. Sadovský and M. Drdácký, "Buckling of plate strip subjected to localized corrosion-a stochastic model," *Thin-Walled Structures*, vol. 39, no. 3, pp. 247–259, 2001.

[2] T. E. Dunbar, N. Pegg, F. Taheri, and L. Jiang, "A computational investigation of the effects of localized corrosion on plates and stiffened panels," *Marine Structures*, vol. 17, no. 5, pp. 385–402, 2004.

[3] T. Nakai, H. Matsushita, N. Yamamoto, and H. Arai, "Effect of pitting corrosion on local strength of hold frames of bulk carriers (1st report)," *Marine Structures*, vol. 17, no. 5, pp. 403–432, 2004.

[4] H. Matsushita, T. Nakai, N. Yamamoto, and H. Arai, "Effect of corrosion on static strength of hull structural members (1st report)," *Journal of the Society of Naval Architects of Japan*, vol. 2002, no. 192, pp. 357–365, 2002.

[5] T. Nakai, H. Matsushita, N. Yamamoto, and H. Arai, "Effect of corrosion on static strength of hull structural members (2nd report)," *Journal of the Society of Naval Architects of Japan*, vol. 2004, no. 195, pp. 221–231, 2004.

[6] D. Ok, Y. Pu, and A. Incecik, "Computation of ultimate strength of locally corroded unstiffened plates under uniaxial compression," *Marine Structures*, vol. 20, no. 1-2, pp. 100–114, 2007.

[7] D. Ok, Y. Pu, and A. Incecik, "Artificial neural networks and their application to assessment of ultimate strength of plates with pitting corrosion," *Ocean Engineering*, vol. 34, no. 17-18, pp. 2222–2230, 2007.

[8] Y. Zhang, Y. Huang, and F. Meng, "Ultimate strength of hull structural stiffened plate with pitting corrosion damage under unaxial compression," *Marine Structures*, vol. 56, pp. 117–136, 2017.

[9] A. Rahbar-Ranji, N. Niamir, and A. Zarookian, "Ultimate strength of stiffened plates with pitting corrosion," *International Journal of Naval Architecture and Ocean Engineering*, vol. 7, no. 3, pp. 509–525, 2015.