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Optimum Design of Polymer Composite Reactor Pressure Vessels †

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Abstract: Based on DBR, a pressure vessel and standard vessel are designed using a public view and diagrams. They are formulated to a standard specification using the ASME pressure vessel code rules and the European standard EN13445. The pressure is determined under influence of a closed end. There are limitations to the structure of the container. Using DBA, several analyses were performed based on FEM to provide parameters to complete the DOE, and combined with DFA and DFM to verify that the analysis was conducive to giving users a good analysis plan. The core premise of this study is to simplify operation, to provide an exemplary user interface, observe various parameters according to requirements, meet pressure requirements during the reaction of polymer composite materials, and ensure that the temperature, strength, and manufacturing cost are within safety factors, to provide a good user experience.

Keywords: DBR; DBA; FEM; DFA; DFM; UI/UX

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1. Introduction

A polymer composite reaction pressure vessel is a reaction vessel for heating, pressure detection, control, automatic stirring, etc., and automatic operation. They are manufactured to different parameters according to additional product requirements [1]. Nowadays, Industry 4.0 and IoT have become the trend. In addition to accurately controlling incoming and outgoing raw materials through intelligent monitoring, human errors can be reduced to improve the stability of production [2].

1.1. Design Requirements

In addition to conforming to the Design for Assembly (DFA), being easy to assemble and disassemble, and having a structural strength that allows operation at different temperatures and pressures, a polymer composite reaction pressure vessel must be designed to accurately control the dosage of reagents and have a simple easy-to-understand operation panel [3,4]. The goal is to optimize the user's operation through UI/UX (User Interface/User Experience) so that the designer can understand all aspects of the user's requirements, and improve the cross-domain communication efficiency most appropriately [5].

1.2. FEM-Design

The Finite Element Method (FEM) is a widely used method to numerically solve differential equations in engineering and to produce mathematical models. Problems include traditional areas such as structural analysis, heat transfer, fluid flow, mass transfer, and electromagnetic potential. The simple equations that model finite elements are combined into a broader system of equations to model the entire problem [6]. FEM then approximates the solution by minimizing the relevant error function by variational methods, and using Ansys analysis, desired results, and given parameters.

1.3. Introduction to DBA

Design by Analysis (DBA) is intended to complement and replace traditional DBR: this restricted route uses steels and steel castings with sufficient toughness for calculating temperatures below the creep range. The term 'action', which replaces the old term 'load', means a parameter is applied to the structure, such as force (including pressure), temperature, changes, and applied displacements, resulting in pressure or tension [7]. A simple, straightforward composition with environmental pressure is possible, while the flexibility expected of modern code adjusts the safety margin according to the difference of the change in movement, the possibility of a combination of actions, the consequences of failure, differences in structural behavior, consequences of different failure modes, and uncertainty in analysis, which all contribute to the concept of a safety factor. This concept uses different actions, different local safety factors, the different roles of the structure, other failure modes, and the corresponding resistance [8]. The safety factor takes into account actions as well as the resistance of the structure.

2. Quality Improvement Project

2.1. DBA & DBR Approach

The study investigated a double-layer vertical cylindrical pressure vessel (shell) with skirt supports and annular pressure heads, using DBA and DBR, and using ANSYS to classify the study into elastic and inelastic, to analyze structural integrity. Table 1 shows the design specifications. According to the specification, two extremely different steels were selected for investigation: high-strength pressure vessel steel P500-QT and low-alloy steel P355. The proposed work flow is shown in Figure 1. The stress resistance of the design, according to the ASME code, is represented by Equation (1). The allowable design stress resistance is in accordance with the EN13445 European standard. The thickness of the outer cylindrical shell is given by Equation (3). The axial stress resistance (σxy) is obtained using Equation (4). According to the specification, the meaning of a symbol is derived as follows: $Rp(0.2/\mathrm{t})$ = Yield value, $R(m/20)$ = UTS, t = Corrosion Allowance, PR = Pressure of Cylindrical Shell Inner Radius, PD = Pressure of Inner/Shell Diameter, SE = Young's Coefficient of Maximum Allowable Design Application:

$$f = \min\left(\frac{R_{p(\frac{0.2}{t})}}{1.5}; \frac{R_{\frac{m}{20}}}{2.14}\right), \tag{1}$$

$$f = \min\left(\frac{R_{p(\frac{0.2}{t})}}{1.5}; \frac{R_{\frac{m}{20}}}{2.4}\right), \tag{2}$$

$$T = \frac{PR}{SE - 0.6P}, \tag{3}$$

and

$$\sigma\mathrm{xp} = \frac{PD}{4t}. \tag{4}$$

Table 1. Cylindrical shell design specification.

Material Properties	P500-QT	P355
Young's modulus, E(GPa)	210	200
Poison Ratio (γ)	0.29	0.28
UTS, σ_u ($R_{M/20}$), Mpa	640	600
Yield value, $\sigma_{y\,(}R_{P0.2/t)}$, Mpa	580	380
Density, ρ(Kg/m^3)	7872	7850

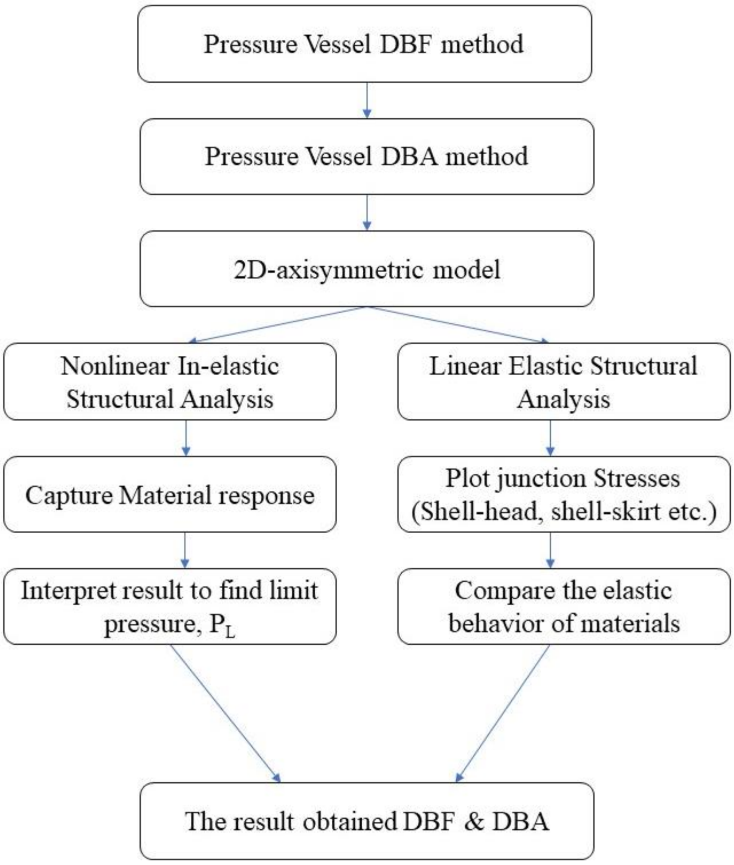

Figure 1. Pressure vessel design by DBA route.

2.2. QFD Result

Customer requirements for QFD include ease of disassembly, durability, and temperature and pressure control [9]. DFM design-optimized processing methods are used to manufacture ideal products and reduce assembly parts through DFA, which is convenient for users during the operation process [10]. In this way, the user can quickly and efficiently take out the experimental product ready for the next experiment. On the other hand, the product is designed following the pressure vessel specification, which makes the product structure more robust, as such it instils confidence in the experimental process, and the equipment is monitored at the same time. It also provides more intuitive and accurate data to users for an accurate and efficient user experience [11].

The DBA/DBR is verified and analyzed to obtain results. Because it is impossible to understand the usage habits and environments of all users, it is necessary to thoroughly discuss how to meet user needs in the design stage to improve the overall product. The cross-comparison of 10 vessels with results from Columns #7 and 6 is in line with customer needs, so it can improve the reliability of this analysis for market users.

3. Conclusions

According to the design method of QFD, it is understood how to meet customer's expectations; DBA/DBF are used to produce an equation for research vessel design that meets design specifications and to obtain corresponding design parameters, and the products can have detailed data to enable comparison. The pressure vessel is optimized through FEM. Feedback for real-time monitoring of temperature and pressure provides a variety of I/O interfaces, adjusts the stirring speed as needed, and avoids many problems encountered by traditional reaction vessels. The visual window is used to observe the reaction process of chemical materials, accurately control the input and output of materials, avoid parameter errors that lead to poorly finished products, automatically stir the reaction, and make the reaction process more complete. Finally, the IoT function gives users an entire real-time operating experience, which reduces human errors, increases the controllability of the finished product, and improves the fluency of the overall operation. Finally, an integral anti-corrosion material is made to avoid damage to the pressure vessel caused by different chemical materials through high-temperature and high-pressure reactions.

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