Simulation Analysis of The Thickness Effect Towards Mechanical Aspects in The Design of Centrifugal Pump Casing

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Abstract. The strength of the centrifugal pump is crucial to ensure the safe pump operating when endure to unintended pumping condition. The presence of the solid particles and sudden increase of pressure may lead to the damage on the casing of a centrifugal pump and it becomes critical when the thickness of the casing is thin. This study aims to investigate the effects of the thickness on the mechanical aspects such as stress, strain and displacement in the casing design by using finite element (FE) analysis. The structure of the pump casing with various thicknesses is analyzed via FE-based software. The correlation of the wall thickness with the mechanical aspects is studied. The critical region with high stress was spotted in the simulation. The simulation results revealed the wall thickness demonstrated a polynomial correlation to the displacement and strain. The stress of the casing showed the linear correlation with the thickness. The critical region was noticed at the intersection region of the pump casing. The mechanical aspects of the pump casing were improved with the increment of the wall thickness in the pump casing design.

1. Introduction

The centrifugal pump is widely used in the industry to transfer the liquid [1]. The single stage and multistage centrifugal pump is commonly used in a manufacturing sector and the mining sector. The impeller and the casing is a main component in a centrifugal pump. The performance of the centrifugal pump incorporates with the head, the brake horsepower and the capacity of the pump was mainly based on the design of the impeller [2]. The design parameters of centrifugal pump such as the number of blades, the diffuser, and the blade height, blade angle, blade width, the diameter of the impeller and the volute radius must be accurately designed to ensure the highest performance. The complex liquid flow in the pumping process influenced the centrifugal pump performance [3]. The unsteady flow inside the volute of the centrifugal pump may cause the decrease in efficiency, creating noise or causing damage to a centrifugal pump [4]. Therefore, the structure of the centrifugal pump must be strong enough to maintain the functionality of the pump.

The strength of the pump’s structure can be analyzed in the finite element based software [5,23]. The design parameters are improved based on the simulation results. With the aid of the simulation tools [6], the research and design optimization can be performed before the fabrication of the actual pump. This is advantageous for the long term product design and development. The simulation analysis is not only limited to the structural analysis [7], it also includes the fluid flow analysis [8]. Moreover, it is widely...
applied in various industry-related problems or engineering problems such as wave soldering [9], reflow soldering [10], plastic encapsulation process [11], IC encapsulation [12], injection molding [13], molded underfill process [14], reflow oven flow study [15,16], biomechanics [17] and 3D stacking chip [18]. The commercial simulation software was utilized to create and simulate the structural and fluid flow models. Both structural and fluid software was integrated in solving the fluid-structure interaction phenomenon [19] for the industry problem. The simulation analysis is also integrated with optimization method such as Taguchi [20] and response surface methodology [21]. Besides, various decision making methods such as Analytical Hierarchy Process and TRIZ [22] were also incorporated with the simulation analysis to predict and suggest the solution for manufacturing process.

The design enhancement of the pump casing can be achieved via the conceptual design method [23] with the aid of simulation analysis. The understanding of the structure in terms of mechanical helps the improvement of the design parameters. In this study, a centrifugal pump casing was considered in the structural simulation analysis. The 3D model of the centrifugal pump was created and meshed by the finite element based simulation software. The thickness of the pump casing was varied to study the correlation with respects to the mechanical aspects. Besides, the critical region with high stress, strain and displacement was investigated on the pump casing. The stress distribution of the pump casing was also visualized in the results. This study is expected to provide the understanding of the centrifugal pump casing design and the simulation result is useful as the references for the engineer.

2. Methodology

This study focused on the structural analysis of the centrifugal pump casing via the simulation technique. Various casing thicknesses were considered in this study to investigate its effects toward the stress, strain and displacement in the critical region. The 3D model was created and meshed in the software. In the simulation, the load of water pressure was assumed to be a constant and it was applied on the internal surface of the pump casing. Figure 1 shows the 3D meshed model of the centrifugal pump and the boundary conditions.

![Figure 1. 3D meshed model of the centrifugal pump in the structural analysis.](image)

Five different thicknesses of the casing were considered, which are 1 mm, 2mm, 3 mm, 4 mm and 5 mm of wall thickness. Various materials such as aluminium alloy [24, 25], ceramic [26] and cast iron-GG 25 [27] have been used to fabricate the centrifugal pump. The material used in this study for the pump casing is cast stainless steel and the properties are summarized in table 1. During the simulation, the uniform internal pressure (2.117 MPa) was applied on the internal surface of the casing to mimic the pressure induced by water in the maximum operating condition. The critical region and mechanical
aspects of the pump casing were analyzed after the completion of the simulation. The correlation between the thickness and mechanical aspects was highlighted in the study.

Table 1. Material properties of cast stainless steel used in the simulation.

| Properties         | Value      |
|--------------------|------------|
| Elastic modulus    | 190 GPa    |
| Poisson ratio      | 0.26       |
| Shear modulus      | 79 GPa     |
| Mass density       | 7700 kg/m³ |

3. Results and Discussion
A grid sensitivity test was carried out on the 3D meshed model of a centrifugal pump to determine the suitable mesh size that predicts the consistent and accurate result on the mechanical aspect. In this study, five mesh sizes were considered in the grid sensitivity test and stress versus mesh size is plotted in figure 2. The grid sensitivity test indicated 5.5 mm of mesh size overestimates the stress in the structural analysis. The mesh size ranging from 5.6 to 5.9 mm shows the convergence of the simulation results. Therefore, 5.8 mm of mesh size was considered in the current study.

Figure 2. Grid sensitivity test for different mesh sizes.

Figure 3 shows the critical region of the stress in the centrifugal pump casing. The maximum stress concentrated in the intersection region between the discharge nozzle and the casing. This intersection region separates the discharge nozzle and the compartment of the impeller. Therefore, this region was critical and need to pay attention to the design of the pump casing. The thickness of the casing was designed from 1 mm to 5 mm in this simulation study. The changes in the thickness resulted in the variation of mechanical aspects (table 2) The simulation results revealed the increment in the thickness of the casing has reduced the stress, displacement and strain gradually. The thin casing (1 mm) endured the highest stress 598.87 MPa. The stress decreases almost 11% when 2 mm of thickness was used. The increase of thickness to 5 mm resulted in 26% of stress decrement. This indicates the thickness of the casing is a significant design factor. Similarly, the use of 5 mm thickness also caused the decrement of strain (18%).
Figure 3. The critical region and stress distribution of the centrifugal pump casing for 3mm of thickness.

Table 2. Simulation results for different thicknesses of casing in the critical region.

| Thickness of casing (mm) | Stress (MPa) | Displacement (mm) | Strain   |
|--------------------------|--------------|-------------------|----------|
| 1                        | 598.79       | 0.6478            | 0.0022   |
| 2                        | 531.28       | 0.6462            | 0.0020   |
| 3                        | 528.54       | 0.6458            | 0.0019   |
| 4                        | 479.08       | 0.6453            | 0.0018   |
| 5                        | 442.82       | 0.6451            | 0.0018   |

Figures 4-6 show the plot of the mechanical aspects versus the thickness of the pump casing. The plots revealed the correlation for thickness with stress, displacement and strain. The stress around the critical region reduces gradually when the thickness of casing increased from 1 mm to 5 mm. The stress demonstrates the linear relationship with the thickness. The R-square (0.95) indicates the linear relationship fitted the data. Besides, the displacement and strain show the polynomial behavior to the changes of thickness. The R-square for both plots are 0.97, which means 97% of data fitting. The displacement and strain slightly decreasing with the increment of casing thickness. This situation indicated the resistance to the displacement or deformation for a thicker casing is better than a thin pump casing. The use of 4 mm and 5 mm thickness shows a minor deviation in the displacement (0.03% of the difference) and strain as clearly shown in figures 5 and 6. Therefore, this can be suggested that the use of 4 mm could minimize the material consumption in the fabrication of the pump casing, when compared to 5 mm of thickness.
**Figure 4.** Stress against thickness of pump casing

**Figure 5.** Displacement against thickness of pump casing

**Figure 6.** Strain against thickness of pump casing
4. Conclusions
The simulation analysis of the thickness effect towards the mechanical aspects in the design of centrifugal pump casing was successfully carried out by using the finite element based software. The current results revealed the thickness of the pump casing is one of the crucial design parameters that influence the structure of the casing. The design of thin centrifugal pump casing may lead to the higher stress concentration. The increase of thickness to 5 mm reduces 26% of the stress and 18% of displacement in the critical region. The critical region of the pump casing was noticed at the intersection between the discharge nozzle and the casing. The results clearly indicated that mechanical aspects of this region can be minimized by the increase of thickness. The thickness of the pump casing exhibits the linear correlation with the stress and polynomial behavior was observed in the displacement and strain. However, the application of 4 mm and 5 mm thickness yielded slightly changes in displacement and strain. The findings of the current study are expected to be useful in the design of the centrifugal pump casing. Moreover, the study on the effect of volute design for the centrifugal pump casing is proposed for the future work.

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