

# Structural Analysis of a Commercial Passive Lower Limb Exoskeleton

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**ABSTRACT** – Past studies on the structure of the passive lower exoskeleton mostly focused on prototype exoskeletons which were fabricated using aluminum alloy. However, minimal attention has been paid to analyse the structural strength of the low-cost commercial sit-stand exoskeleton, particularly the ones made of PVC. The aim of this study is to quantify the deformation, strain, shear stress and safety factor of a low-cost commercial passive sit-stand exoskeleton. The Granta EduPack and finite element program in ANSYS<sup>®</sup> software were applied to simulate the structural analysis of the exoskeleton frame. This study concluded that the PVC material has contributed the highest deformation, shear stress, and strain, which can diminish the structural strength of the sit-stand exoskeleton.

## 1. INTRODUCTION

In the era of Industrial Revolution 4.0, exoskeleton technology is significant to ease workers in executing manufacturing operations. Exoskeleton is a wearable tool that is designed to strengthen or provide additional support to the body of the users. In industrial workplaces, exoskeletons are commonly used for manufacturing operations such as manual lifting. Exoskeleton technology can be classified into two types, active and passive. One of the examples of the passive lower limb exoskeleton is sit-stand exoskeleton. The sit-stand exoskeleton enables a worker to perform tasks in sitting or standing postures, and he or she can walk around without obstructing the workspace. Engineering analysis on the structure of the sit-stand exoskeleton is vital to ensure that it is capable to support body weight and safe for users.

Past studies on the sit-stand exoskeletons have been focusing on the structural analysis of the prototype exoskeletons which were fabricated using aluminum alloy [1-2]. However, a little attention has been paid to analyse the mechanical strength of the commercial sit-stand exoskeleton. In this study, a low-cost commercial lower limb exoskeleton (Figure 1) used for sitting and standing tasks was chosen to analyse its structural strength. The exoskeleton has two sides (right and left legs). The main material of the exoskeleton's structure is polyvinyl chloride (PVC) plastic. The objective of this study is to compare the deformation, strain, shear stress and safety factor of the exoskeleton structures made of different materials such as PVC, structural steel,

galvanized steel, and aluminium (5052). Additionally, this study had performed a minor design modification on the thigh support of the commercial sit-stand exoskeleton to improve its structural strength. Findings of this study are certainly important for exoskeleton designers to develop a sit-stand exoskeleton that is safe for users.



Figure 1 The low cost commercial lower limb

## 2. METHODOLOGY

Mechanical engineering analysis on the structure of the low-cost commercial sit-stand exoskeleton was started by developing a computer aided design (CAD) drawing of the exoskeleton using SOLIDWORKS software by Dassault Systèmes. PVC was set as the material for the main structure of the exoskeleton. Concurrently, this study performed analysis of materials selection using Granta EduPack to identify other materials that are most appropriate for the exoskeleton structure by considering availability, cost effectiveness and satisfying mechanical strength.

Next, this study executed the simulation of static structural analysis within the whole part of the exoskeleton assembly. The finite element program embedded in ANSYS<sup>®</sup> software was used to analyse the deformation, strain, shear stress and safety factor of the exoskeleton structure. The analysis simulation was performed on one side (leg) of the exoskeleton including thigh support, lower stand, support rod, and joint link were simulated. The maximum load used in the analysis was 60 kg (588.6 N), which is half of the maximum weight of Malaysian population [3]. The subsequent analysis was the parametric optimization. The purpose of this analysis is to determine the suitable materials of the sit-stand exoskeleton for functionality and manufacturability.

This study found that the contact area between the thigh support and the lower stand was subjected to the

highest strain. Those parts were reshaped by rounding or filleting the sharp edges or corners of the contact area. After this modification, the parametric optimization was run again to quantify deformation, strain, shear stress and safety factor of the redesigned structure.

### 3. RESULTS AND DISCUSSION

Figure 2 illustrates the results of the structural analysis associated with deformation (A), strain (B), and shear stress on the original material (PVC) of the commercial exoskeleton structure.

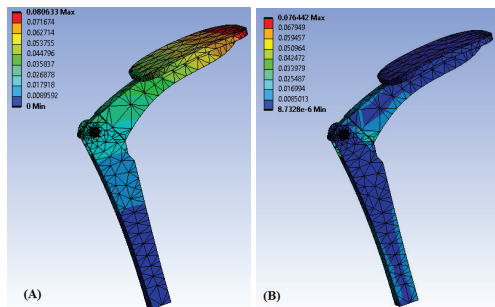


Figure 2 Structural analysis on the exoskeleton structure

As for the parametric optimization, the following materials were suggested as options to the PVC: structural steel, galvanized steel, and aluminum (5052). These materials were ranked based on their availability. Table 1 shows the results of maximum deformation, strain, shear stress, and safety factor of different materials which are vary significantly. The structural steel has obtained the best performance in terms of the least deformation, aluminium has the lowest number of strain, and the galvanized steel is good to overcome shear stress.

Table 1 Parametric optimization (existing design)

Materials	Deform. (mm)	Strain (mm <sup>-1</sup> )	Sheer Stress (MPa)	Safety factor
PVC	80.63	0.076	3854.36	0.027
Structural Steel	1.37	0.0015	86.34	0.8642
Galvanized Steel	1.51	0.0014	68.83	1.058
Aluminium (5052)	4.37	0.0012	105.32	0.85

Based on results in Table 1, this study found that the existing material (PVC) of the exoskeleton has contributed the highest deformation (80.63 mm) and shear stress (3854.36 MPa). It was also noted that the highest strain (0.076 mm<sup>-1</sup>) occurred in the thigh support. This study has reshaped the critical area of the thigh support as shown in Figure 3. Analysis of parametric optimization was repeated to quantify new maximum deformation, strain, shear stress, and safety factor. As shown in Table 2, the modification was able to reduce the deformation and the shear stress (except the structural steel).

Based on the results of the parametric optimization, galvanized steel is the best material to minimize deformation, strain, and shear stress for the sit-stand exoskeleton. However, galvanized steel will create a heavy exoskeleton, which sacrifices the user's need - lightweight for easy mobility. As an alternative,

the aluminum provides acceptable structural strength and satisfy the lightweight requirement. This material is also commonly used in designing sit-stand exoskeletons [4-5].

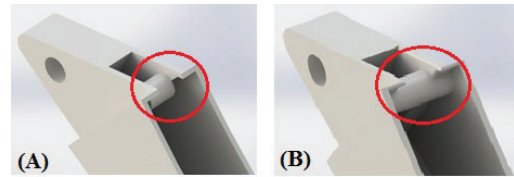


Figure 3: Existing design (A) and improved design (B)

Table 2 Parametric optimization (improved design)

Materials	Deform. (mm)	Strain (mm <sup>-1</sup> )	Sheer Stress (MPa)	Safety factor
PVC	76.14	0.26	3321.77	0.015
Structural Steel	1.26	0.0049	186.46	0.3
Galvanized Steel	1.42	0.0011	46.4	1.48
Aluminium (5052)	4.09	0.0014	43.85	0.71

### 4. CONCLUSION

A simulation of structural analysis was performed on a low cost commercial passive sit-stand exoskeleton to quantify the deformation, strain, shear stress and safety factor of the tool. This study concluded that the PVC material contributed the highest deformation, shear stress, and strain, which can diminish the structural strength of the sit-stand exoskeleton. Aluminum will be the best alternative for a material replacement for the exoskeleton's structure.

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