Develop Dump Truck Body Small Parts from Alternative Materials to Reduce Weight, Carbon Footprint and Cost

James Sier

Tim Sercombe
School of Mechanical Engineering
The University of Western Australia

Deon Wessels
CEED Client: Austin Engineering

Abstract

Manual handling of 'small' components in excess of 30 kg on dump truck bodies increases installation time and risk of injury for workers. Austin Engineering, a manufacturer of dump truck bodies, seek to redesign some of these components (shim pads, rock deflectors, and rock ejectors) using alternative materials to primarily reduce weight, but also carbon footprint and cost. This project aims to quantify the loading conditions of these components and calculate equivalent stress so that suitability of alternative materials can be evaluated. Simulation of operating conditions is conducted in ANSYS Mechanical. At this stage of the project, suitable alternative materials have been identified for each part, and reduce the weight of shim pads, rock deflectors, and rock ejectors by 88%, 92%, and 87% respectively. This paper describes the project process and contains a discussion of results obtained.

1. Introduction

1.1. Background Information

Surface mining operations around the world rely on rigid body dump trucks (Figure 1) to transport raw materials between loading and unloading sites. Austin Engineering are the world's largest non-OEM manufacturer of bodies for these trucks – the structure that contains the raw material – and have historically focused on custom design and innovation of their products.

In 2020, a major client of Austin requested weight reduction of a particular component of these bodies to reduce the difficulty of installation of the part, which requires a large degree of manual handling. This request motivated Austin to launch an investigation into several similar parts through the CEED program and with an expanded scope.

Three small parts on dump truck bodies have been identified for consideration in this study; namely shim pads, rock deflectors, and rock ejectors. Furthermore, in addition to weight, carbon footprint and cost have been targeted as properties for reduction.

Figure 1 Loading of Austin Engineering's Ultima truck body atop a CAT793F dump truck (Austin Engineering, n.d.)

1.2. Problem Statement

The project aims to investigate how weight, carbon footprint and cost of the parts listed above can be reduced through the use of alternative materials, with the goal of improving the marketability of truck bodies.

Each part is currently made from a mild steel, primarily due to its historical availability. The primary concern with steel is weight (Evans, 2015), which makes installation more difficult and unsafe; each of the parts of interest in this study requires some amount of manual handling during fabrication and installation.

Austin are also looking to become more sustainable and eco-friendly in alignment with current decarbonisation trends in the mining industry; steels are a relatively eco-unfriendly material regarding CO_2 emissions during production (Jones, 2019).

Cost reduction is also an important factor to consider when improving the marketability of truck bodies, however the availability of steel does make it a viable option in this category.

2. Process

2.1. Literature review and background research

Investigation for each part commenced with a review of each part's function to allow accurate formation of boundary conditions for the FEA models as well as provide some context to the motivation behind altering material properties for them. This process primarily involved communication with Austin staff and examination of documents provided by Austin, but some information on part failure and procedures was found online.

2.2. Model construction and analysis

Determining the loading conditions and structural requirements of each part is the primary exercise within this project; the actual material investigation is comparatively minor despite the project title. Structural analysis is conducted within ANSYS Mechanical under the static structural and explicit dynamics analysis systems, depending on which part is being considered. 3D models of each part are constructed in SolidWorks based on drawings provided by Austin.

2.2.1. Shim pads

The static structural analysis system was used to construct the shim pad model. Load from the truck body and payload is distributed across two sets of four shim pads, with the front-most pads taking the most weight and hence are the focus for the final analysis to reduce computation.

Load distribution across all pads was first determined by constructing a rough large-scale model containing the truck body, payload, truck chassis, and all shim pads. A combined mass exceeding 200 t for the truck body and payload was used, which rotate together about a rear pivot (Figure 2). Only load on the front pad from this analysis is used in the final model, where a dynamic load factor is applied based on past EDEM simulation conducted at Austin to capture the effect of dropping material into the body.

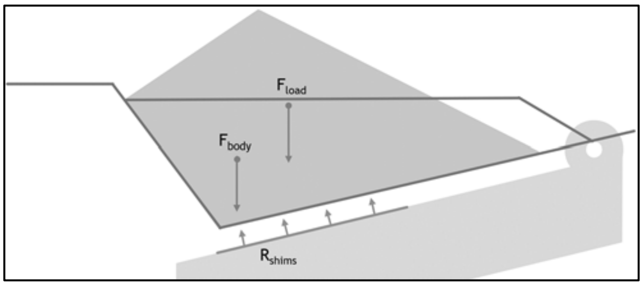

Figure 2 FBD of shim pad system.

2.2.2. Rock deflector

The explicit dynamics analysis system was used to construct the rock deflector model. A large rock was dropped onto the deflector from a low height, and maximum stress during the initial impact period (0.01 s) is measured. Rock size and weight vary depending on the type of material mined and the specific mine site, but in general the size of rock used is on the upper end of what can be reasonably expected (L. Greeshaw, personal communication, January 29th, 2021).

2.2.3. Rock ejector

Despite the nature of the rock ejector's operation (rocks pushed into the ejector via tyre rotation), the static structural analysis system was used to model this part due to the low tyre speed of these trucks. Force required to eject a rock varies greatly, and a large part of modelling this system stems from quantifying this value. This force was approximated by calculating the confinement force on a rock of a given size due to tyre pressure after becoming lodged (Figure 3). This force is applied to one end of the ejector bar, which acts as a cantilevered beam.

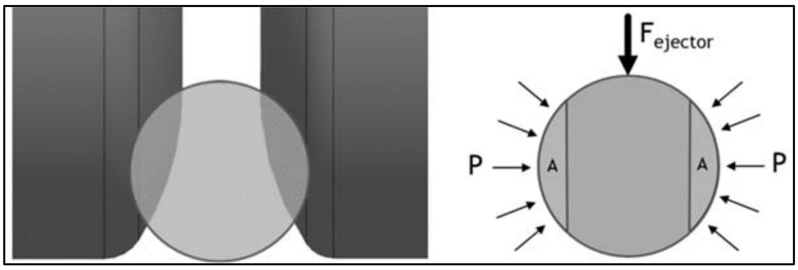

Figure 3 Illustration of rock lodged between rear tyres and simplification of applied forces.

2.3. Material search

Results from the above analysis are used to find general material categories using the online material database MatWeb. Specific materials and grades are determined by contacting suppliers. Candidate materials are then substituted into the ANSYS models to validate suitability.

3. Results and Discussion

Table 1 below contains a summary of the stress results for each part under the loading conditions described above. These values are used to inform material suitability prior to simulation with alternative materials.

	Shim pad	Rock deflector	Rock ejector
Max stress (units)	1	100	70
Current safety factor	>100	3-5	10-15

Table 1 Maximum stress in each part under maximum loading conditions. Stress values normalised from 1-100

Figures 4, 5 & 6 below illustrate the stress distribution in shim pads, rock deflectors and rock ejectors respectively. These indicate where maximum stress occurs and can be used for future work involving altering part geometry through topology optimisation.

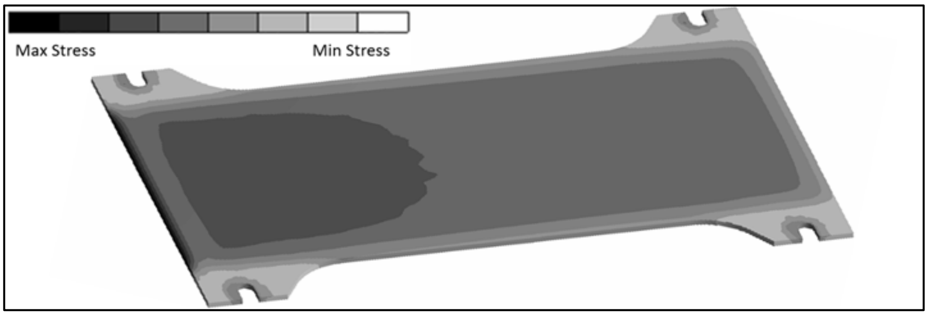

Figure 4 Shim pad: Equivalent von-Mises stress distribution (darker = higher stress)

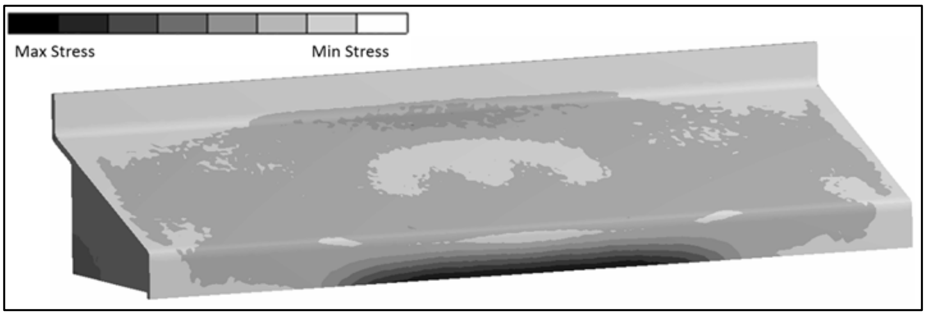

Figure 5 Rock deflector: Equivalent von-Mises stress distribution (darker = higher stress)

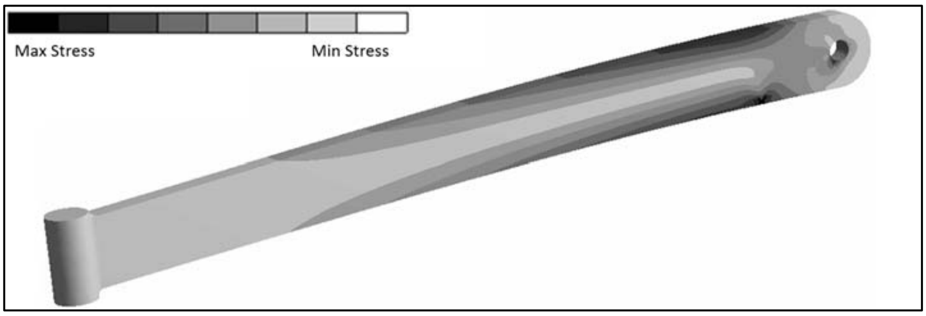

Figure 6 Rock ejector: Equivalent von-Mises stress distribution (darker = higher stress)

Each part has a high factor of safety, indicative of a lack of prior analysis and a historical "If it's not broken, don't fix it" approach to the design of these components – steel was originally selected for its availability, not suitability. At this stage and using these results, one candidate material has been determined for each part with relevant properties summarised in Table 2 and discussed below. Weight and cost have been quantified where data is available. A qualitative assessment only of carbon footprint reduction at this stage is also provided.

	10 mm Shim pad		
	Weight (kg)	Cost ($/unit)	Carbon footprint
Current	X_W	X_P	
Material A	$0.12X_W$	$0.53X_P$	Recycled
	Rock deflector		
	Weight (kg)	Cost ($/unit)	Carbon footprint
Current	Y_W	Y_P	
Material B	$0.08Y_W$	$0.61Y_P$	Recycled
	Rock ejector		
	Weight (kg)	Cost ($/unit)	Carbon footprint
Current	Z_W	Z_P	
Material C	$0.13Z_W$	N/A	

Table 2 Alternative materials and associated weight, cost and carbon footprint reduction qualities.

As evident by the results above, materials A and B are suitable candidate materials for shim pads and rock deflectors, improving upon all three project aims. Maximum shim pad stress is below the yield strength of material A, indicating its suitability. Suitability of material B for rock deflector use, however, is not as simple to determine.

Evaluating material suitability for the rock deflector system presented a unique challenge in that the dynamic nature of the system makes maximum stress heavily dependent on the stiffness of the material. More flexible materials absorb the impact force over a greater distance due to increased deformation and hence have lower maximum stress. Maximum stress for the deflector could therefore not simply be matched to the yield strength of a candidate material as with the other parts. Analysis of this system required potential candidates to be studied in more detail, with a greater number of total simulations performed. Material B was originally selected for the shim pads, but was then tested on the rock deflector and found to be suitable.

Determining suitable materials for the rock ejector was more difficult. Load on the ejector is much higher than the other parts, and cannot be reduced by using a more flexible material in the manner described above. A composite material was selected due to the compromise between strength and weight, as well as allowance of some deformation before failure. Stock profiles of this material are not available in the same dimensions as the original steel bar, and so additional analysis with this new geometry was conducted to support the result achieved here. This profile is more mass-efficient at handling the loading conditions of the rock ejector (primarily bending), and so part of the mass reduction is attributed to the geometry.

4. Conclusions and Future Work

Steel currently used for shim pads and rock deflectors can be replaced by sheets of material A and B to achieve the weight, cost and carbon footprint reduction outcomes identified in the project scope. Material C can replace the steel used for rock ejectors to achieve weight reduction, but at a projected increased cost (actual cost data not currently available).

Analysis of the rock ejector is not yet complete due to the uncertainty surrounding the magnitude of load applied, and may affect the final material choice once additional work is conducted.

Alteration of part geometry is another method that can be used to achieve similar results to material substitution. While not within the scope of this investigation, future work in this area could improve upon the results of this project and incorporate elements of topology optimisation to do so. As noted in the discussion of the rock ejector, some analysis of altered part geometry has already occurred due to the availability of material C.

5. Acknowledgements

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