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DESIGN OF A BEVERAGE CAN CRUSHER: A LEAN THINKING SOLUTION FOR ENVIRONMENTAL SUSTAINABILITY IN FOOD AND BEVERAGE INDUSTRIES

Enesi Y. Salawu
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Azeta Joseph
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Fajobi Muyiwa
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Joseph Dirisu
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Ajayi O.O
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Felix Ishola
Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State,

Nigeria

ABSTRACT

The study focused on the design of an aluminium can crusher that can be used domestically to crush empty beverage can and return them to the industry in order to encourage sustainability in the beverage manufacturing sector. Some properties of steel and aluminium which include Young's modulus, density, yield strength and poisson's ratio were used in the design calculation and simulation of the crusher. Each of the component part and the complete assembly of the machine was modelled using SolidWorks. The machine was further evaluated by testing with samples of aluminium can which showed about 60% reduction in the weight of the tested samples SimulationXpress Analysis Wizard in SolidWorks was further employed to simulate the Von Mises stress distribution and displacement on the rammer being the essential part that actually carry out the crushing. This was equally done to determine the *crushing resistance and the reliability of the machine. The result of the simulation of the rammer showed that the machine will stand crushing stress and the factor of safety of more than one (1) showed that the machine will be highly efficient in operation.*

Keywords: Production, Machine, Modelling, Stress Analysis

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1. INTRODUCTION

Lean system of production is a recognised approach for sustainable manufacturing. This is evident in reduction of waste and environmental pollution especially in recycling of beverage can [1, 2]. Food and beverage production firms have been facing the challenge of recycling their waste can thereby leading to environmental pollution [3]. Despite the use of crushed beverage can in reinforcing and stabilizing engineering structures, there is still difficulty in their local harvest and turning them to useable forms because of the unavailability of the necessary device [4,5]. According to Ulsen et al [6], the design of crushing machine will entail the size and micro-fracture, and this will help in the crushing process. Further to this, the impact force required for crushing the beverage can must be adequately designed into the machine for increased efficiency [7, 8]. Thus, increasing the rate of recovery of can loss during production and preventing environmental pollution [9]. Previous study by Johansson and Evertsson [10], revealed that crushers of adequate capacity and reliable power gives maximum performance thus improving production, rate of can recovery and environmental protection [11, 12, 13]. Obviously, uncompressed cans occupy a lot of space and this requires creative and innovative idea to combine components into a reliable machine for crushing the aluminium cans [14]. Consequently, attempt to crush aluminium cans with bear hands or feet will definitely result into time and energy wastage. Therefore, crushing of aluminium cans is based on compression principles and the study of modelling of the dynamic forces involved is critical to the design of the crusher [15, 16, 17, 18, 19]. However, the simulation behaviour of the crushing process is possible to predict the stress applied, know the operation performance of the machine and determine the wear of the crusher [20, 21,22, 23]. Also, it is important to note that the variation in the crushing behaviour with height of the can during the compression process is critical to the crushing stress [24, 25, 26]. This play a major role in influencing the mechanical properties and shape of can deformation [27, 28, 29]. More so, it is fundamental in engineering design that the mass of impact on the machine causes strain hardening because of the dynamic response during crushing [30]. In the present work, a can crusher was developed to address the recycling problem associated with cans. It is designed to crush one can at a time when compared with industrial crusher that are into the business of recycling thereby saving the cost of producing new ones. The crusher requires less effort, and this can be used in individual home for cane crushing as well as reducing the space occupied by thrashed cans.

Nomenclature

n= factor accounting for the end conditions

E= young's modulus (G pa)

I= mass moment of inertia (m^4)

L= length of column (cm)

D= Lid thickness of the can (m)

σ = Normal force stress ($\frac{N}{m^2}$)

F= force applied (N)

A= Area (m^2)

2. MATERIALS AND METHOD

2.1. Material selection and description of properties

The can crusher mechanism was modelled using mild steel material. Table 1 presents the structural properties of steel and aluminium material used in the design while table 2 presents the Can dimensions

Table 1 Properties of mild steel and Aluminium

	Young's modulus (G pa)	**Density Kg/m^3**	**Tensile Strength (M pa)**	**Yield Strength (M pa)**	**Poisson's Ratio**
Mild steel	150	7850	841	340	0.303
	Young's modulus (G pa)	**Density Kg/m^3**	**Tangent modulus (M pa)**	**Yield Strength (M pa)**	**Poisson's Ratio**
Aluminium	75	2700	28	60	0.303

Table 2 Dimensions of the Can

Radius	**Height**	**Thickness**	**Lid thickness**	**Bottom thickness**
3.3	12.1	0.25	0.3	0.3

2.2. Method

Euler's Column equation was employed to determine the force required to crush a can made of aluminium and is given by:

$$F= n\pi^2 EI/L^2$$ [31].

When the Column is pivoted in both ends, n = 1 and fixed at both ends n = 4 one end fixed, the other end rounded, n = 2, one end fixed, one end free, n = 0.25

Where d = 0.003 m (Thickness on the lid of the can) as this is the only part that is in contact with the crushing surface.

$$E = 69 \times 109 \text{ N/m2}$$

$$L = 0.121 \text{ m}$$

we choose our n to be 4 as this give us the maximum force employable and also fit the condition of having both ends fixed.

To calculate the mass moment of inertia which is given by the equation;

$$I = \pi d^4/64$$ [32].

Therefore, $I = \pi \times 0.003^4/64$

$=3.976 \times 10^{-12} m^4$

Hence the force will be

$(4x\ \pi^2 \text{ x } 69 \text{ x } 10^9 \text{ x } 3.976 \text{ x } 10^{-12}) / 0.121^2$

= 739.75 N

The Compressive stress effect by the crushing surface can be evaluated using

$$\sigma = \frac{F}{A}$$

Diameter of the top lid = 0.0541m

Thickness of the top lid = 0.003m

Area of Can = $(\pi \text{ x } d^2) / 4$

$= (\pi \text{ x } (0.0541\text{-}0.003)^2) / 4$

$=2.051 \text{ x } 10^{-3}\ m^2$

Stress = $739.75\ N / (2.051 \text{ x } 10^{-3})\ m^2$

=360.677 KPa

2.2.1. Solidworks Simulation of component parts and assembled Can Crusher

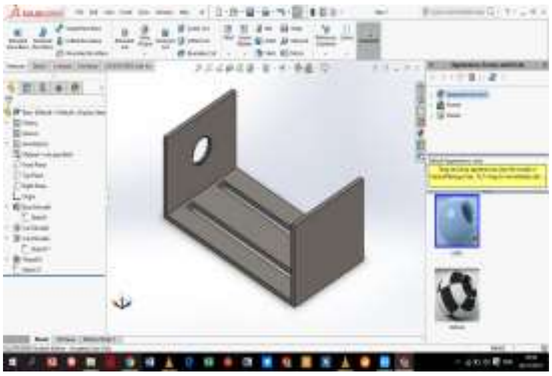

Figure 1 Base

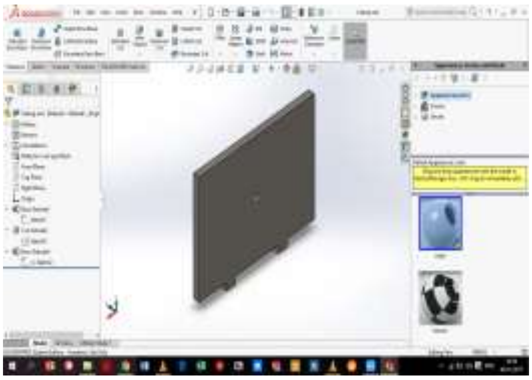

Figure 2 Rammer

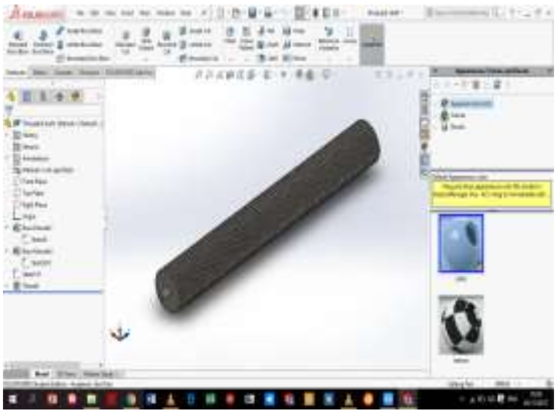

Figure 3 Threaded Shaft

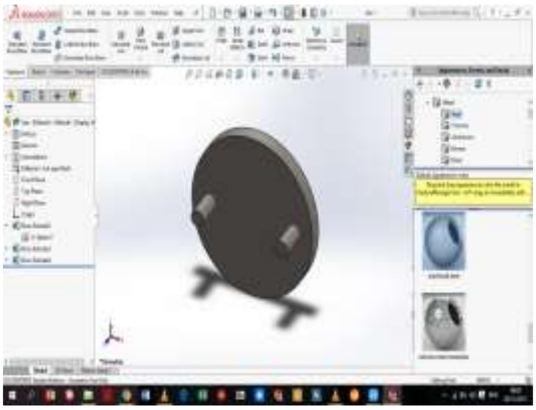

Figure 4 Handle

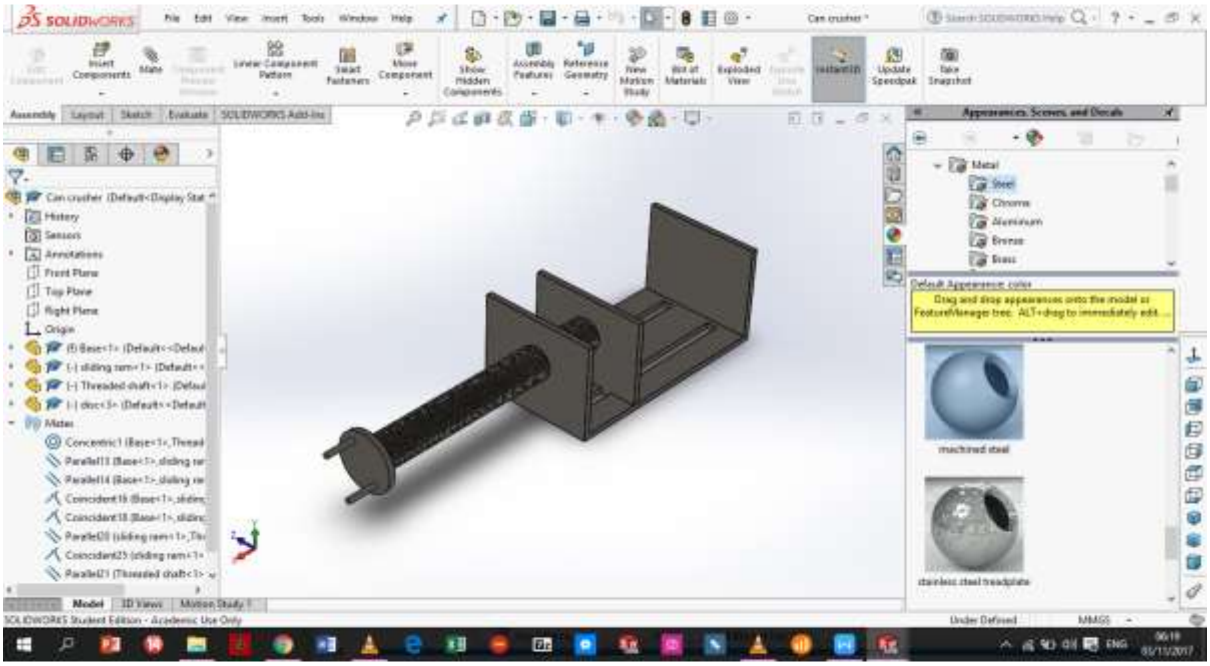

Figure 5 Assembled Can Crusher

3. RESULTS AND DISCUSSION

Figure 1-5 presents the various component part model and the complete assembly of the crusher in SolidWorks. The crusher was loaded with a sample of can to determine the crushing efficiency before loading more. This was continued with addition of more load into the crusher until the crushing limit was achieved. The rammer carried out the main purpose of the design hence there is need for further simulation result of the stress impact on the rammer using SimulationXpress Analysis Wizard in SolidWorks. Figure 6-8 presents the simulation result of the variation in stress and displacement of the rammer during operation.

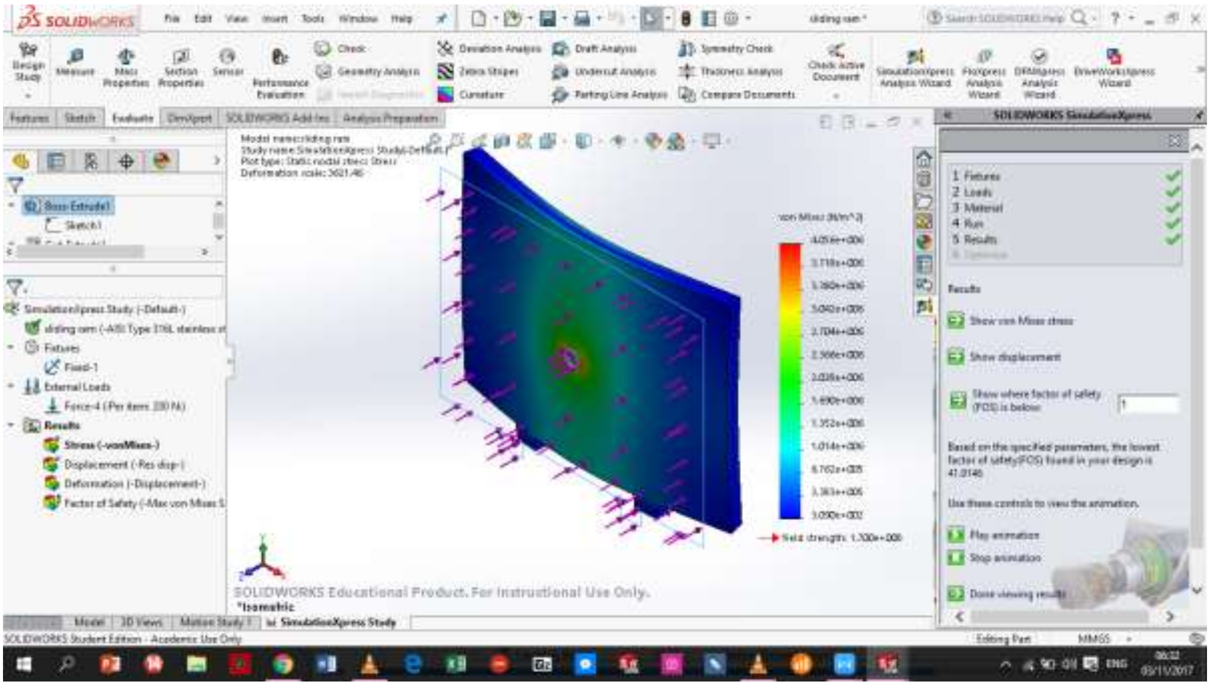

Figure 6 Variation of Stress in the Rammer

It could be depicted from figure 6 that the colour variation in stress represent the variation in the Von Mises stress distribution. For instance, Von Mises stress of about 3.09e+002 Pa can be observed in the blue regions also the yellow regions described the regions of Von Mises stress of about3.142e+006 Pa. However, the material having a von Mises yield strength of about 1.700e+008 Pa will not easily deform; hence the rammer will function effectively without failure.

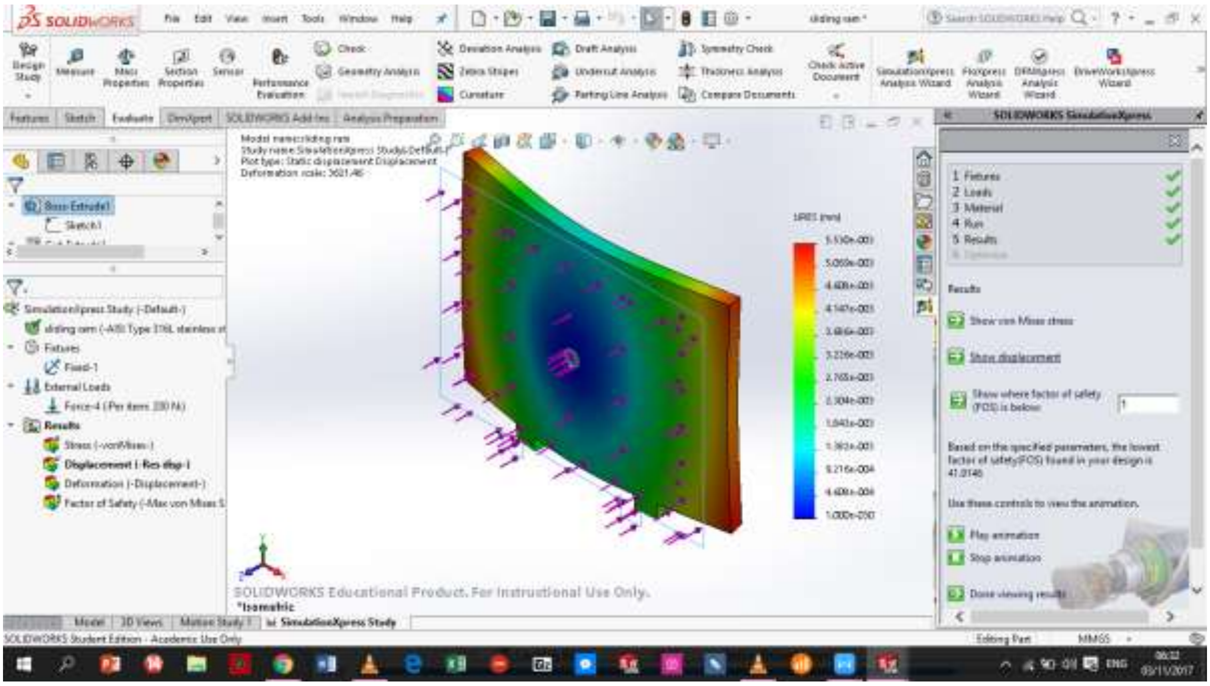

Figure 7 Variation in Rammer Displacement

Figure7 also presents the various displacement of the rammer indicated by different colours.

The response to displacement by the rammer can be observed on the blue regions corresponding to a value of von mises displacement of about 1.000e-030 mm, other displacement values include; 1.82e-003 mm, 2.304e-003 mm,4.147e-006 mm, and 5.530e-003 mm respectively denoted by different colours. The variation in the displacement of the rammer showed the position and overall reliability of the developed device.

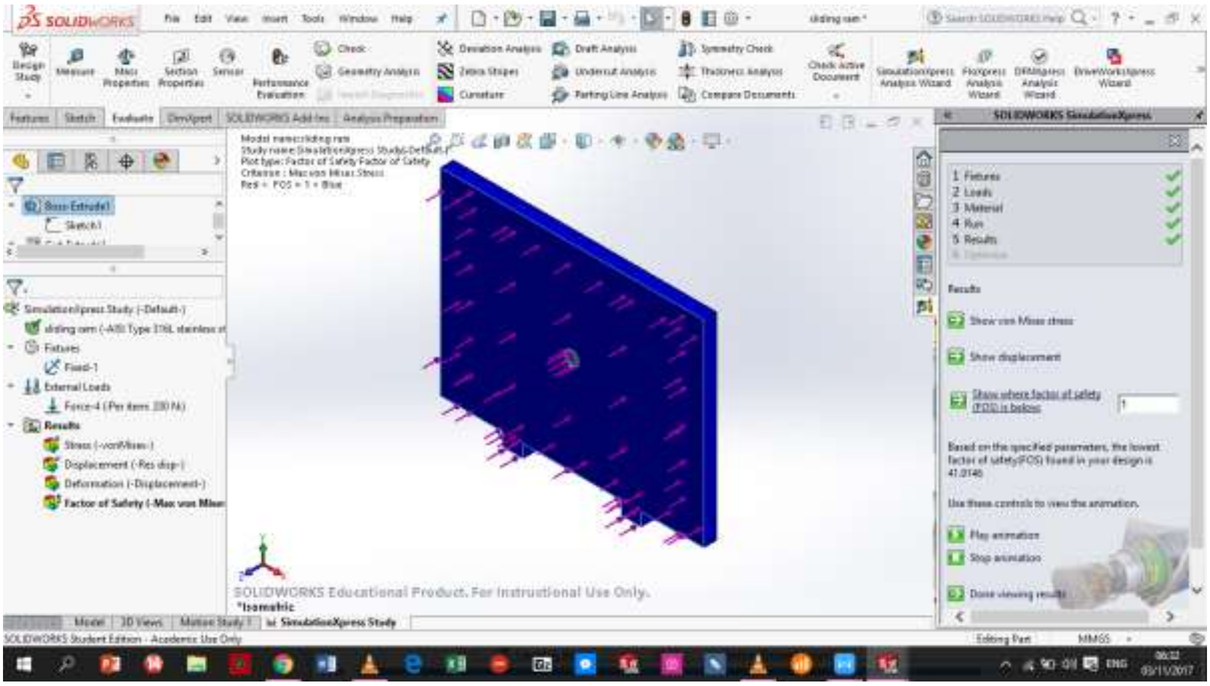

Figure 8 Effects of variation in Rammer Factor of Safety

Also figure 8 displayed the simulation result of including factor of safety in which the safety is increased to withstand any eventual failure. The entire blue area indicate that the factor of safety is not below one (1), this indicate the safety and reliability of the developed crusher.

4. CONCLUSION

A domestic aluminium can crusher was designed using mild steel for the whole component. Each component was further simulated using SolidWorks Express wizard to predict their behaviour while in use. The design involved clearance, interference, mass properties and moment of inertia as it interacts with plane of contact to determine the geometric tolerance required by the crusher. The result showed that certain magnitude of force is required to cause the deformation. In addition, the design calculation proved effective in evaluating the crushing impact on the machine. Furthermore, samples of beverage can were used to test the efficiency of the crusher which yielded about 60% volume reduction of samples. Thus, the innovation has provided an alternative waste recovery approach for consumers of beverages in can within their remote areas to recycle their empty cans and turn them to wealth. Also, this will sustain the manufacturing sector of the economy in the area of recovery and recycling of waste can at reduced cost.

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