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Design, Finite Element Simulation and Optimization of the Back Plate in Wet Grinder

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Abstract. The purpose of this study is to investigate the reason for the failure of the back plate in the wet grinder manufacturing company and to improve the design for getting a quality product. In general, experimental studies tend to be time-consuming and expensive for failure analysis. So, numerical methods such as finite element modelling (FEM), is used for investigating the cause of failure. In spite of the fact that finite element analysis has been frequently used as a means of investigating the design failure, small empirical evidence exists in the literature that it is used in the wet grinder manufacturing industries. Systematic analysis of the failure enables the wet grinder manufacturing organizations to eliminate or reduce the failure and to survive in the competitive environment. For this purpose, finite element analysis is conducted on a three-dimensional model to investigate the reason for real-time failure. The simulated model is validated against the failed product. In addition to the finite element analysis, regression analysis and response optimisation are performed to examine the effects of the parameters such as the rib thickness, positioning of bearing stem and backplate material on the critical load and weight of the backplate. A regression equation is formed to select the optimum parameters so that the von-mises stress and deflection are less. The optimum parameters were modelled and analysed to verify the results obtained in the response optimization. Finally, an optimized design is proposed with suitable material and design modifications to overcome the failure of the back plate.

Keywords: Backplate, Finite element analysis, Regression analysis, optimization, Von-mises stress.

INTRODUCTION

Increased competition among companies forced manufacturing companies to produce quality products [1]. Hence, industries are forced to adopt innovative approaches and techniques in order to improve the performance of the product and systematically evaluate the reason for failure if any. But, manufacturing companies that manufacture wet grinders practice conventional and non-scientific evaluation of customer complaints and failures [2]. After the invention of the wet grinder by Mr. P. Sabapathy and team, many different types of wet grinders were designed and introduced in the market to make it more user-friendly. Constant and continuous developmental efforts were made to improve the existing models of wet grinders suitable for the kitchens [3]. Generally, the wet grinder is considered advantageous over mixer grinder because the stone in the grinder does not generate a lot of heat. The heat produced can change the flavour of the food. Also, the stones in the wet grinders do not lose their sharpness as quickly as that of metal blades used in mixer grinders. Hence wet grinders have a longer life compared to mixer grinders [4]. Customers continue to prefer using wet grinders for preparing the batter. Due to which there is a steady growth in the wet grinder manufacturing industry [5]. Wet grinder manufacturing companies which are mainly small and medium-sized is expected to achieve a 20 per cent growth per year. Owing to the potential growth rate, recently multi-national companies started penetrating the wet grinder manufacturing market and the contemporary manufacturers are forced to make quality products. Hence it is the need of the hour to enhance the quality of the products that are manufactured by the traditional manufacturers.

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The research work being reported in this paper was carried out in a wet grinder manufacturing industry located in Coimbatore, which accounts for nearly 75% of the share of wet grinder manufacturing in India [6]. The author of this paper done this research, realizing the importance of improving the service life of the products, by reducing or eliminating the frequent customer complaints. There were frequent customer complaints on the failure of the back plate. Whereas, back plate forms the heart of the wet grinder, as it supports all the grinding components such as drum, motor. On the basis of the field study, a thorough literature review was carried out to find out the work done in the wet grinding industry.

To the best of the author's knowledge, there is meagre research on the systematic analysis of the component failure reported in the literature. Hence, the scope of this research is to investigate the reason for the failure in the back plate and propose suitable solutions. Finite element analysis is carried out to investigate the reason for failure. The simulated model is validated and regression analysis and response optimisation are performed to establish the effects of the design parameters on the failure of the back plate.

LITERARTURE REVIEW

The literature has been reviewed from the perspectives of wet grinders and FEM applications between 2000 and 2018. The researches on wet grinders mainly reported in wet grinding of food grains and energy consumption. There is one paper on the redesign of the manufacturing system of the wet grinder manufacturing industry. As energy consumption is out of the scope of this study it is not reported in this paper.

Wet-ground rice gives the finest food particles sized 10–30 μm than dry ground flour and semidry ground flour[7]. Moreover, the damage caused to the starch of the food grains in wet grinding is less. The characteristics of solid loss, water absorption and moisture content were observed on the textural characteristics of soybeans at various soaking times and four different soaking temperatures by Pan &Tangratanavalee. It was found that when the soaking temperature increased from 30°C to 40°C the solid loss also increased considerably [8]. After evaluating the crushing strength of rice with soaking time, it was observed that there is a significant decrease in the hardness of the rice upon hydration [9]. High soaking temperature notably reduces the soaking time required. Energy consumption and grinding characteristics, of parboiled and raw rice in various wet grinding systems, namely, mixer grinder, wet grinder and colloidal mill were evaluated by a researcher. It was concluded that the duration of grinding had an inverse effect on the particle size and direct impact on the starch damage as well as energy consumption [10]. Different grinding techniques were investigated on chemical and functional properties during the grinding process of rice grains into rice flour. Proximate analysis revealed that dry ground flour had the highest carbohydrate, protein and lipid contents. Wet grinding technique yielded flour that exhibits significantly finest average particle size distribution (9.32μm), with significantly lowest damaged starch (4.08%) and the highest L* value (93.55) [11]. A study analysed the physical and chemical properties of nine varieties of rice in dry grinding and wet grinding processes It was revealed that wet grinding process resulted in flour with significantly lower protein and higher carbohydrate content [12].

A complete Value Stream Mapping (VSM) for the current manufacturing system was carried out and a future value stream mapping was proposed for productivity improvement [2]. Few pieces of research on wet grinding of food ingredients and manufacturing system redesign have been reported in the literature arena, whereas papers reporting the researches on analysing and improving the component of wet grinders are found to be rare.

Finite Element Method was used to estimate the crashworthiness of circular tubes under different lateral loading condition for different geometric parameters and the results were used for optimisation [13]. An Equivalent Static Load Structural Optimisation (ESLSO) was carried out for non-linear materials by utilising Finite Element Method [14]. Optimisation of a bicycle frame for vertical and lateral stiffness was carried out with bar elements using parametric finite element analysis[15]. Structural Optimisation of the blades of a Vertical Axis Wind Turbine (VAWT) was carried out using parametric FEA and genetic algorithms. This helped in significantly reducing the mass of the blades without compromising its efficiency [16].

Statistical approaches such as regression analysis and response optimisation are also employed to analyse the effect of different combinations of parameters of a component. A regression model was used to predict the probability of tire failure due to various design parameters [17]. An extensive, parameter-free shape and thickness were carried out to minimise the stress developed in a component [18]. The effect of microcapsule size and concentration of medium catalyst on the mechanical properties of self-healing Glass Fiber Reinforced Plastic (GFRP) composites was done using multi-response optimisation [19]. For optimising the sintering parameters of Al-Si alloy/fly ash composite, response optimisation techniques were used [20].

CONSTRUCTION AND WORKING OF TABLE TOP WET GRINDER

The construction and working of the table top type wet grinder are shown in Figure 1. An electrical motor is used for driving the drum assembly. The driving pulley in the electrical motor is connected to the driven pulley in the drum assembly with the help of a V-belt. Drum assembly is made of food-grade stainless steel drum and special stone base glued to it. Cylindrical or conical shaped grinding stones are fixed in the roller holder with a spring, inside the drum assembly. Drum and the grinding stones rotate and grind the soaked grains and lentils. The base frame is an ABS molded back plate that supports the electrical motor, drum assembly and all the other components. All the electrical and drive components are covered by the outer shell.

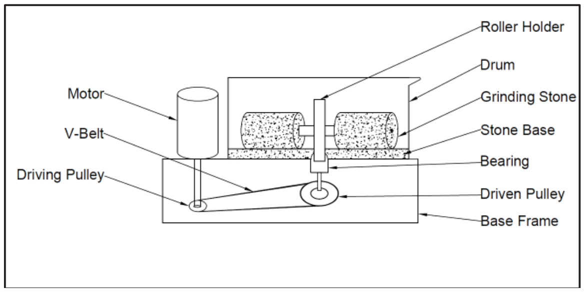


FIGURE 1. Schematic Diagram of the Table Top Wet Grinder

The number of components and the manufacturing process in the wet grinder varies from one company to another [14]. There are 50 different components assembled in the type of wet grinder that was considered for the study. The construction of one typical table top wet grinder model in one of the case study company is discussed in this section. The details of the backplate are shown in Figure 2.

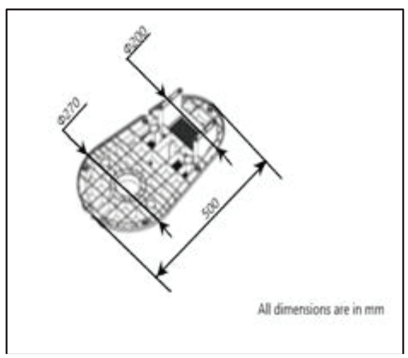


FIGURE 2. Details of the Back Plate

STATIC ANALYSIS OF THE FINITE ELEMENT MODEL

Finite Element Modeling

When building a high-performance wet grinder, great thought is paid to the designing of the backplate, eliminating the stresses by forming smooth radius by grinding the sharp edges. Shot-peening technique is used to induce compressive stresses on the surface for better performance. During brainstorming, it was proposed to analyse the design of the back plate and the material. The existing material in which the back plate is made is Acrylonitrile butadiene styrene (ABS) polymer. The structural strength of the existing backplate needs to be strengthened to avoid deflection. Hence, a suitable material with durability is proposed. The proposed material is cost effective to improve the market competitiveness of the grinder.

Finite element modelling was carried out to analyse the stress and structural deflection of the backplate. A 3D solid model was created in solid works as shown in Figure 3 and the back plate model is exported to ANSYS as an IGES file for finite element analysis.

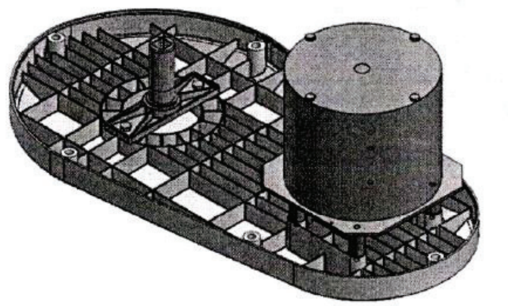


FIGURE 3. Model of the Back Plate Created Using SolidWorks

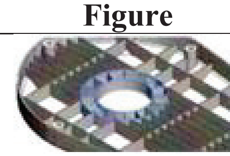
Element Type

Three dimensional structural solid, SOLID 185 in ANSYS built-in element library is used for the analysis. The element has three degrees of freedom at each node namely translations in x, y and z directions.

Boundary Conditions

It is assumed that the base plate is resting evenly on the floor with four pads. Hence all the degrees of freedom on the nodes corresponding to the resting pads were arrested. The motor and bearing are modeled as lumped masses. Load 1 and load 2 represents the dead weight of the drum, grinding stone, motor and other components. Whereas load 3 and 4 represent the dynamic load encountered by the back plate during running condition but only its equivalent static force is applied on the plane and faces respectively. During running the dynamic load due to the grinding components will induce an opposite force to the motor. Hence load 4 is represented as negative. The loads acting on the back plate are shown in Table 1.

TABLE 1. Forces Acting on the Model

Load Name	Magnitude	Type	Plane of Action	Illustrative Figure
Load 1	28 kgf	Normal force	Bearing stem seating (1 face)	
Load 2	4 kgf	Normal force	Motor mounting pads (2 faces)	
Load 3	25 kgf	Normal force	Bearing stem seating (1 face, 1 plane)	
Load 4	-25 kgf	Normal force	Motor mounting pads (2 faces, 1 plane)	

Mesh Details

The maximum element size of 20mm and minimum element size of 4 mm with high quality 4 point Jacobian solid curvature based mesh is used for meshing the back plate. Various iterations were done using coarse and fine mesh for finding the optimum elements that give consistent stress and deflection values.

Assumptions in Analysis

- The material obeys Hook's law, showing linear elastic behavior: the stress initially increases rapidly in direct proportion to the strain.
- There is no need for thermal analysis as the model during running condition will not rise above 40ºC.
- All the components like motor, bearing stem are rigidly connected.

Finite Element Analysis

The current material for the backplate is ABS polymer and the material properties are shown in Table 2.

TABLE 2. Material property of ABS polymer

Tensile Strength	Density	Thermal expansion coefficient	Poisson's ratio	Yield limit
42.5 MPa	1.05 x 10^3 Kg/m^3	10.1 x 10^{-5} /°C	0.35	60.6 - 73.1 MPa

Results for stress values and deflection values for the existing back plate (ABS) material are shown in Figure 4. The stress and deflection values show the maximum von-mises stress of 73 MPa occurs in the bearing stem area. This acts as a stress riser which can lead to failure. This stress riser is to be avoided by rounding of the radius.

The deflection is shown in figure 5 at the bearing stem area which is a maximum of 6.59mm.

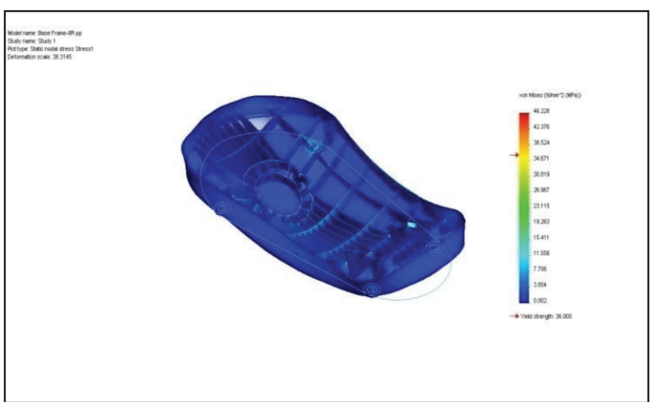


FIGURE 4. Stress Plot of the Existing Back Plate with ABS

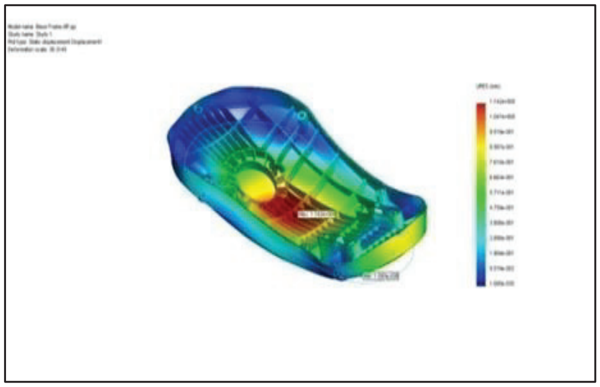


FIGURE 5. Deflection Plot of the Existing Back Plate with ABS

Verification of Finite Element Model

The validity of the FE model was evaluated by comparing the results obtained in the simulated test with those observed in the regression analysis. It is observed that a good qualitative agreement exists between the two. Also, the solid model of the back plate with a weight of 1.6 kg matches the actual weight of 1.5kg of the product.

STATISTICAL ANALYSIS FOR FINDING OUT THE RELATIONSHIP BETWEEN THE PARAMETERS

Regression Analysis

The analysis of the back plate using Finite Element Analysis is accurate but is highly time-consuming to evaluate the effect of different combination of parameters. This has been overcome by using regression analysis and response optimization techniques. Minitab statistical software has been employed for this purpose. The initial dataset for regression analysis was collected from the results of Finite Element Analysis. The data sets used for regression comprised of material, the load applied, bearing stem position, number of additional ribs, the thickness of additional ribs, Young’s modulus, weight, cost, deflection and Von-Mises stress. Among these data sets, the deflection and Von-Mises stress have been made the response variables for the regression analysis. The load applied number of ribs and rib thickness has been assigned as continuous variables since they comprise of a wide range of values. However Young’s modulus, bearing stem position, weight and cost have been assigned as categorical variables since they contain a finite number of categories or distinct groups. About 40 different combinations of parameters were used for regression analysis.

The following were the parameters used for regression analysis:

Material: ABS and Polypropylene 30% GF
Ribs: with and without additional ribs.
Rib thickness of the additional ribs varied as 2mm, 3mm and 4mm.
Load applied varied between 320N and 640N.
The bearings stem position: Parallel or perpendicular to the motor pad.

The results of the regression analysis showed that the model has a good fit since the R^2 value was around 82.73%. The residual plots also revealed that the model meets its initial assumptions. The p-values of the variables were also less than the significance level of 5% (0.05). This indicates that there is a statistically significant relationship between the response variables and the predictor variables. The obtained regression equations are shown in table 3 and table 4.

In the following tables,

- x denotes the load (in Newton).
- y denotes the number of additional ribs.
- z denotes the thickness of additional ribs (in mm).

TABLE 3. Regression Equations for Von Mises Stress

Bearing Stem Position (Degree)	Youngs Modulus (GPa)	Von Mises Stress (MPa)
Parallel to motor pads	2.4 (ABS)	70.1+ 0.19 x– 1.13 y- 14.75 z
Parallel to motor pads	6.895 (PP 30% GF)	39.7+ 0.19 x– 1.13 y- 14.75 z
Perpendicular to motor pads	2.4 (ABS)	31.1+ 0.19 x– 1.13 y- 14.75 z
Perpendicular to motor pads	6.895 (PP 30% GF)	0.8+ 0.19 x– 1.13 y- 14.75 z

TABLE 4. Regression Equations for Deflection of Back Plate

Bearing Stem Position (Degree)	Youngs Modulus (GPa)	Deflection (mm)
Parallel to motor pads	2.4 (ABS)	8.40 + 0.01 x - 0.61 y- 1.72 z
Parallel to motor pads	6.895(PP 30% GF)	8.52 + 0.01 x - 0.61 y- 1.72 z
Perpendicular to motor pads	2.4 (ABS)	5.83 + 0.01 x- 0.61 y- 1.72 z
Parallel to motor pads	6.895 (PP 30% GF)	5.95 + 0.01 x- 0.61 y- 1.72 z

Response Optimisation

The regression equations were further used to generate data for about 80 different combinations for the back plate. This model was then analyzed using response optimization. In response optimization, the targets used were deflection, Von-Mises stress, weight and cost. The goal was set in such a way to minimize deflection and Von-Mises stress whereas target values was set for weight and cost. The optimal solution obtained suggested 8 additional ribs, the thickness of ribs as 3mm, bearing stem position as parallel to the motor mounting pad and the material as Polypropylene 30% GF. The obtained results were in agreement with those obtained from finite element analysis.

TABLE 5. Optimum Parameters Obtained from Response Optimization

Material	No. of additional ribs	Thickness of ribs	Bearing stem position
Polypropylene 30% GF	8	3mm	Parallel to the motor mounting pad

Improvement Analysis

Simulation Analysis: Case 1

Additional ribs were added to strengthen the bearing stem area for the existing back plate (ABS) material. Using regression analysis, the optimum number of additional ribs was found as 8 with rib thickness of 3mm. Also, it is desired to have a perpendicular bearing stem position to minimize stress and deflection. The maximum von-mises stress of 46 MPa occurs in the bearing stem area. These additional ribs strengthened the bearing stem area and the deflection at the bearing stem area is a maximum of 1.14mm.

Simulation Analysis: Case 2

In order to further reduce the stress and deflection change in material was proposed. The proposed material is Poly Propylene 30% Glass filled material for the new structure with additional ribs. Figure 6 shows the maximum von-mises stress of 34 MPa occurs in the bearing stem area. The deflection is shown in Figure 7 at the bearing stem area which is a maximum of 1.19mm. Figure 8 shows the Factor of Safety plot and it was found to be 1.9.

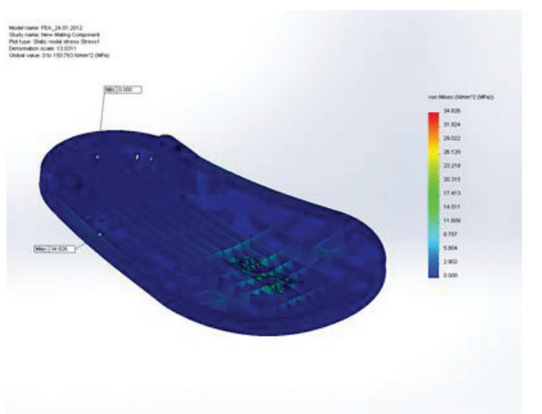


FIGURE 6. Stress Plot of the Modified Backplate with PP 30%

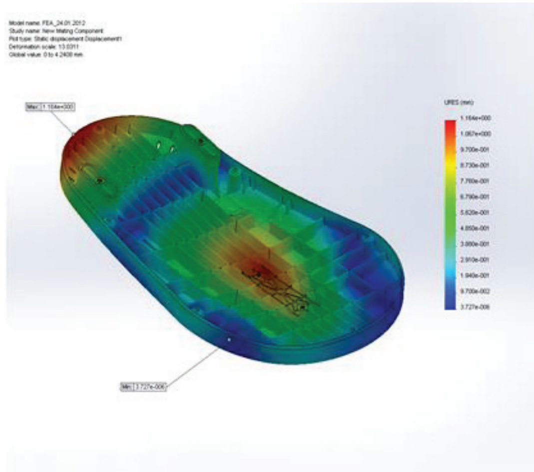


FIGURE 7. Deflection Plot of the Modified Backplate withPP30%GF

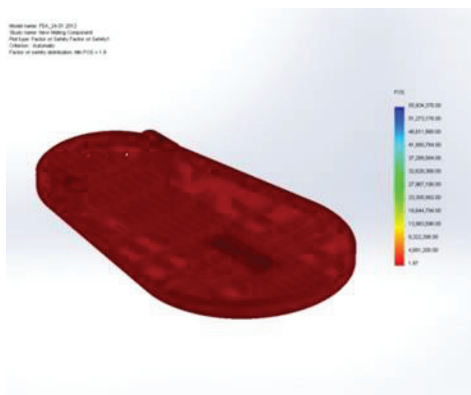


FIGURE 8. Factor of Safety Plot of the Modified Backplate with PP30%GF

RESULT ANALYSIS

Results for stress values and deflection values of all three cases are compared in Table 6. Maximum von-Mises stress for the new modified model with ribs and Polypropylene 30% glass filled material is 34MPa which is less than the tensile strength of 66MPa.The Maximum deflection is 1.16 mm which is within permissible limit. The Factor of safety for the new modified model with ribs and Polypropylene 30% GF material is 1.9. Therefore the design is safe for the redesigned structure of the backplate.

TABLE 6. Comparison of Finite Element Analysis Results

Analysis Cases	Description	Von Mises stress (MPa)	Deflection (mm)
Analysis of the existing model	Material: ABS Condition: existing	73	6.59
Simulation Analysis: Case 1	Material: ABS Condition: Modified with additional ribs	46	1.14
Simulation analysis: Case 2	Material: PP 30% GF Condition: Modified with additional ribs	34	1.16

COST ANALYSIS

Cost analysis is carried out between the existing material and the proposed PP 30% Glass Filled. Since the component is outsourced and purchased from the vendor there is a direct saving on the material cost. Direct labor and expenses, remains the same for both the components. The difference in cost for the back plate of one unit is as shown in Table 7.

TABLE 7. Cost comparison for Different Backplate Materials

Description	**Cost / component in Rs**
Existing ABS material	195
Proposed PP30% Glass filled material	136
Difference	59

TABLE 8. Annual Savings

Number of components manufactured in a year	6000 units
Annual savings for the company	Savings/grinder x No. of grinders/year =Rs 59 x 6000 =Rs3.54,000/year
Percentage of savings per unit	30 %

The cost of the backplate is reduced by 30% and hence there is a direct saving of Rs3,54,000/year to the company by changing the material to from ABS to poly propylene 30% Glass filled.

CONCLUSION

The geometric modeling, regression analysis, finite element modeling of the back plate was carried out to understand the structural behavior for the failure of the back plate. A solution was given to one major complaint that is the failure of the back plate, by proposing an alternate material with additional ribs that gives structural enhancement. Based on a detailed discussion of different material and structural combination the stress and deflection calculation were done by analyzing the structure using regression. A regression equation for finding the stress and deflection of the back plate was formulated. 80 parametrical combinations of the back plate were analyzed in response optimization using the regression equation, in which the targets used were deflection, Von-mises stress, weight and cost. The goal was set in such a way to minimize deflection and Von-mises stress. The optimal solution obtained was 8 additional ribs of thickness 3mm at the bearing stem position need to be incorporated. The author recommended replacing the existing ABS material with Poly Propylene 30% GF as the change in material maintains the same function by reducing the cost of the component.

In this case study, the following benefits were obtained.

- The number of back plate failure during the warranty period was reduced and also there are fewer customer complaints about the failure of the back plate.
- The reliability of the product is increased by substituting alternate material in place of the one that is currently in use.
- The improved backplate is 30% cost-effective than the existing back plate
- The optimized geometry is 10% lighter in weight.
- The back plate has better structural behavior because of the additional ribs.

This study utilizes a systematic approach to the analysis of the failure of the back plate, considering the variable parameters. This approach is essential because most industries manufacturing wet grinders deal with the component failure in a non-scientific manner. This research study fills the literature gap by analyzing not only from a theoretical viewpoint but also from the implementation viewpoint, testing the suitability of the product in a real-time environment. Further study and be done by doing service life testing and suggesting alternate composite materials.

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