Metal Air Battery Shell Unit Redesign with DFMA Aspect and Rapid Prototyping

Moin Ahmed Khan, Gangadhar Angadi, Ankush Raina

Abstract: ***The metal air batterie signify an entirely diverse innovation, which means that the batteries can't be recharged merely through reversing the current. Instead the Anode metal i.e. the spent metal should be replaced by unused fresh ones. The Anode metal electrode can thus be termed as a kind of fuel and the spent fuel i.e anode is completely recyclable and completely ecofriendly as it does not emit any harmful byproducts / zero emission. These metal air batteries can be used in any sort of application where the electricity is required as the metals which are been used in it have huge energy density. To manufacture this battery with minimum cost the DFMA technique should be employed in design approach to get the optimum results of ₹ 40 (Rupees) in cost reduction, further manufacturing capability of the product was been checked with the plastic mould flow analysis for the plastic parts by which the Clamping force of 88.62 Tonne and Fill time of 10 seconds for the cell shell was determined, proceeding to which the prototype was built to check the functionality and aesthetics of the product. This paper is focused on the incorporating the DFMA technique in the design approach and analysis of the part for its manufacturability in mass production process and building up of the proto model with the product cost comparison of the initial design to the redesigned product with the DFMA technique is been analyzed.***

Index Terms: ***Metal Air Battery, DFMA, Manufacturing cost optimization, Manufacturing Cost analysis, Flow mould Analysis, Rapid prototyping.***

I. INTRODUCTION

In the existing situation the necessity of renewable resources stands very vital to withstand in the existing world power requirement as non-renewable resources are extinguishing. Metal air battery are the one of the solutions for the future power requirements as the metal which are used in it as fuel have enormous energy density, high AC/AC efficiency and life cycle, pollution free and low maintenance [1]. Aluminum batteries are the power source of electrical vehicles (EV's) due to abundant in nature, nontoxic, high theoretical energy density (8100 Wh/kg) and specific energy value [2-3]. However, this battery is liable to corrosion, degrade (Its starts once battery turned on) and have not exhibit sufficient cycling performance. Al-batteries are also used as power sources for underwater or remote positioned vehicles[3]. The metal air battery (MAB) receipts the oxygen (O_2) in the atmospheric air as the positive ('+') electrode vigorous material, and take the metal alloy as negative ('-') electrode vigorous material, the O_2 (oxygen) in the air influences the electrochemical reaction interface through the gas diffusion and react with metal alloy to release the electrical energy [4]. For this complete design of metal air battery with the above said process of reaction, the most optimum design should be designed to the accessibility of parts during assembly should not be problem, so standard design procedure to be followed while designing the product. Design for Manufacture and Assembly (DFMA) is hand tailored structure design by the subject matter experts, and syndicates it with parametric design to progress the concept and procedure of DFMA concerned with parametric design [5]. Design for Manufacture and Assembly is used to pre determine the cost of manufacturing and assembly for Fuel Cell power system, and unremitting evaluation for cost depletion [6]. A chief innovation in Design for Assembly application stood thru in 1988 when Ford Motor Company conveyed that Design for Assembly had assisted them to rescue billions of dollars ($) on their Taurus line of automobiles [7]. Injection molding is well-thought-out for mass manufacture of the intricate geometry of plastic products which requires precise dimensions [8]. Rapid prototyping is obliging in situation of complicated and byzantine pattern designs which can't be manufactured by any pattern fabricator with material such as ABS (Acrylonitrile butadiene styrene), PC (Polycarbonate), Nylon [9]. Fusion Deposition Modeling (FDM) parts are strong enough to allow functional testing and the technology allows complex in geometries to be made easily [10].

II. PROBLEM STATEMENT

Nowadays designing a product is not a very big problem but designing of the product to compete with other products in the market which already exists is crucial, so design should be very much simple without affecting the functionality and quality of output from the product by analyzing it for its manufacturability in mass production process to decrease rejection cost as well as direct material cost of it. The product which is been designed should be proved by its functionality so that the proto should be built with the minimum cost to evaluate it.

III. DEIGN OBJECTIVES

The main intension of designing of any product is to work very efficiently for which it is been built, as any product we consider it has its own features of output efficiency.

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The main objective of design in this paper are

1) Assembly simplification of the metal air battery, so that the assembly of it is very ease to assemble.
2) Cost optimization in the design to cut down the direct material cost of the product.
3) Mould flow analysis for identification of the Runner and Gate sizes with Location of it, by which the defects in it's manufacturability in mass production process will be reduce.
4) Verification of design and functionality of part by building a proto model with least cost and less time consumption.

IV. DEIGN METHODOLOGY

The design aspect which is been chosen to design the metal air battery shell is the DFMA technique which has a step by step approach to design any product which is represented as Flow chart in figure 1.

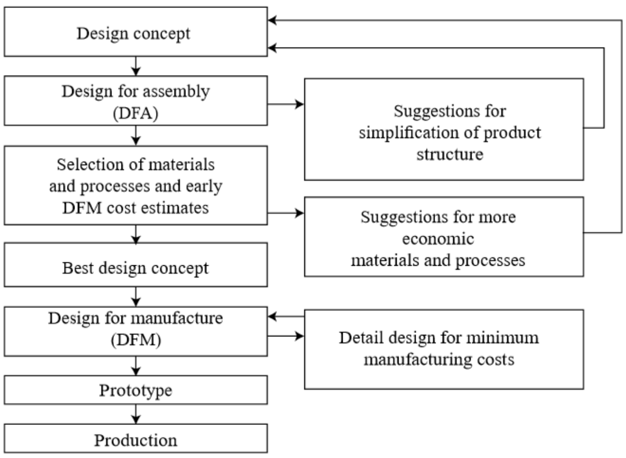

Figure 1: Flow chart of DFMA design approach**.**

In the initial stages the brain storming ideas should be converted in to concepts and further to which how the product is going to be assembled needs designated approach further to which the material and the manufacturing cost should be calculated for each of the concept. The best concept should be picked up and detailed design for manufacturing guidelines should be applied to optimize the parts in the assembly. After all these finalizations of material and the assembly the prototype model should be built to test its functionality.

V. INITIAL DESIGN

In the initial stage the design will be in the conceptual stages so that any idea while brain storming of concepts will be 3D modeled in the Computer Aided Design software's so that it can be visualized for its functionality and its aesthetic look. Since it is in the initial stages it cannot be finalized for its production hence can be further simplified in further to remove the unnecessary parts from the assembly.

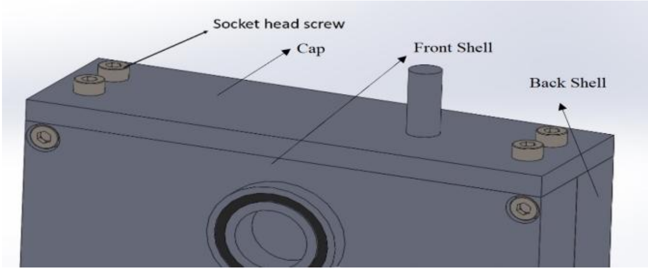

Figure 2 : Initial design

In this design four screws were used to clamp the cap of the metal air battery and four screws to keep the front and the back shell assembled as shown in the figure2.

VI. REDESIGNED PRODUCT WITH DFMA

Further to the initial stage of design the product should be thought for simplification in the assembly of the product, where ever necessary. The reduction of the parts should be done to decrease direct material cost in the product, so that the overall cost of the product will be reduced efficiently. In the construction of metal air battery cell, the shell and the cap are molded out of Plastic which is further been assembled with socket head screws. The complex assembly with screws was replaced by cantilever snap fit hence reducing the cost of the product and assembly time.

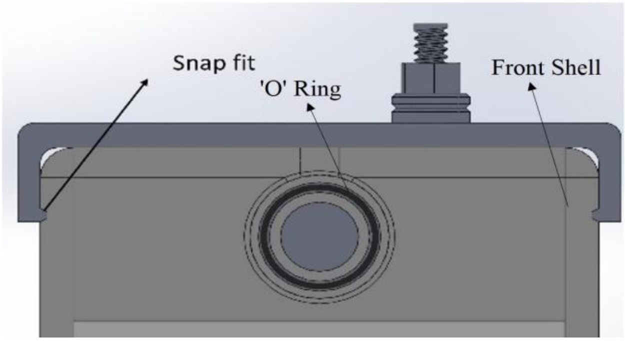

Figure 3 : **Final Design for Cap Assembly With DFMA**

A snap fit is an assembly technique used to attach plastic parts to form the final product by pushing the parts interlocking components together as shown in figure 3. There are a number of varieties in snap fits which includes cantilever, torsional and annular.

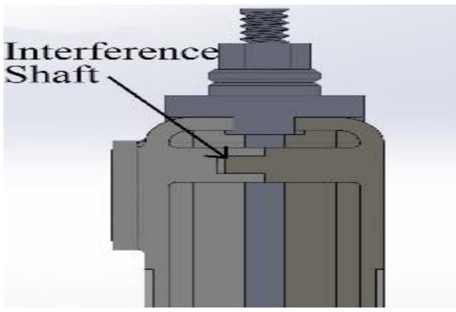

Figure 4 : Final Design for Shell Assembly with DFMA

The Screws for the assemble of the two shell parts of the metal air battery which was a complex assembly was replaced by interference shaft fit as shown in figure 4 hence reducing the cost of the product and assembly time.

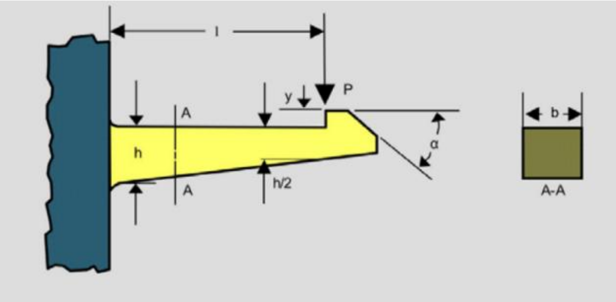

Figure 5: Cantilevr snap fitting hook design general dimension notations

The Input data for the design of snap fit for our design are as per the notations in the figure 5. Data taken as per our requirement in the design of the metal air battery cap

i. Material: ABS (Acrylonitrile butadiene styrene)
ii. Length (1) = 20 mm
iii. Width (b) = 18 mm
iv. Undercut (y) = 2 mm
v. Angle of inclination (a) = 25° (degree)

Determination of wall thickness h, Permissible strain for the ABS material can be taken from the Table 1

Table 1 : Generic allowable short-term strain for snap joints

Material	Short Term Strain (Ɛ)
High Heat PC	4%
ABS	2.5%
Polycarbonate Blends	3.5%
PC	4%

From the Table Ɛ ABS = 2.5 %
Strain required here Ɛ = 1/2 Ɛ ABS = 1.25%
Deflection equation:

$$y = 1.09\,\frac{\varepsilon\, l^2}{h}$$

$$h = \frac{1.09 \text{ X } \varepsilon\, l^2}{y}$$

$$h = \frac{1.09 \text{ X } 0.0125\ X\ 20^2}{2}$$

h= 2.725 mm (Millimeter)

VII. MOULD FLOW ANALYSIS

Mould flow analysis is the process to crosschecking the plastic part for its manufacturability, by examining for its weld lines, air trap and any defects in its manufacturing process by which we can change the design accordingly to overcome the defects in the product before taking it to the final process.

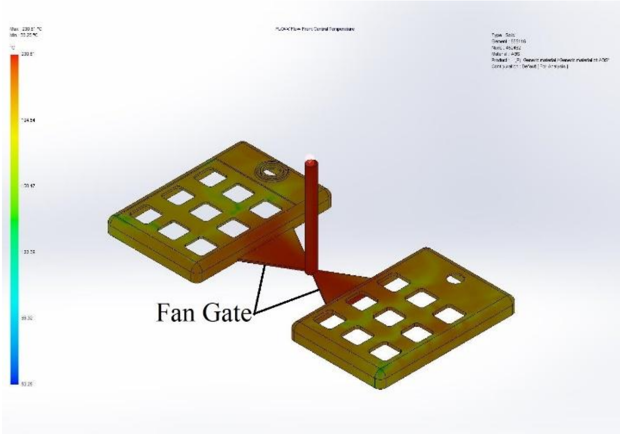

Figure 6 : Part analyzed in Solid works plastics software

Front and the back shell of the metal air battery is been molded in the same die which are called as the family dies, and in the design the gate provided for the plastic part is termed as fan gate as the part is of large projected surface area with thin wall which can be seen in the figure 6. There are some traces of the air traps and the weld lines which do not affect the functionality of the part.

Table 2 : Process Parameters of Mould Flow Analysis

Parameter	Value
Filling time	10.00 sec
Melt temperature	235.00 °C
Mold temperature	50.00 °C
Maximum machine pressure	155.000 Mpa
Packing time	14.300 sec
Filled volume (%)	98.000 %

The Process parameters of the Mould Analysis is been listed in the Table 2, and all the parameters are been optimized by many literation so that the defects should be minimum.

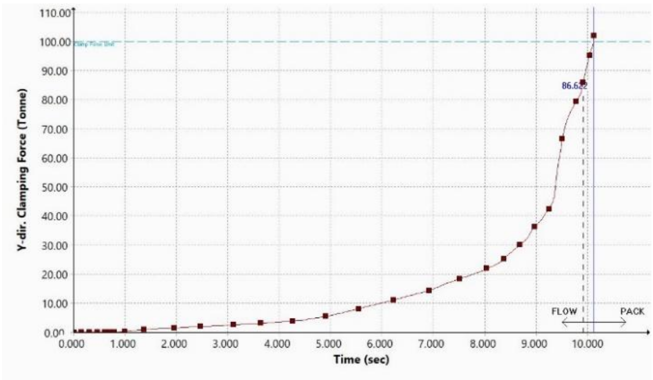

Figure 7 : Clamping Force Vs Time graph in "Y" Direction of Die.

The part filling time was specified as 10 seconds and the clamping force required was 88.62 tonne as our machine has an upper limit of 100 tonne, so this was within the limits of injection molding machine which can be seen in the figure 7 .

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VIII. RAPID PROTOTYPING

Rapid prototyping is the technology by which the parts which have been designed can be manufactured with in less time. Also, to evaluate the part for its functionality and its aesthetic look of the part, in case of an exterior part so that it can attract the customers.

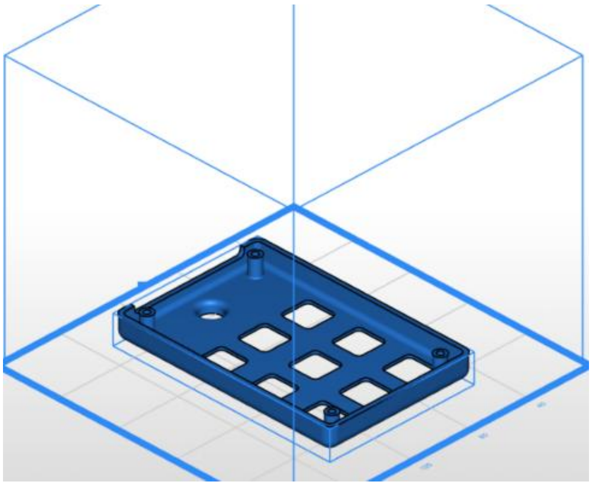

Figure 8 : Part loaded in the Z-Suit software

The 3D cad file has been converted to .stl format so that it can be loaded to the Z-Suit software which is provided by the manufacturer (Zortrax) of 3D printing machine itself is used to generate the z code file, in turn the machine could use the file to build the model which can be seen in the figure 8.

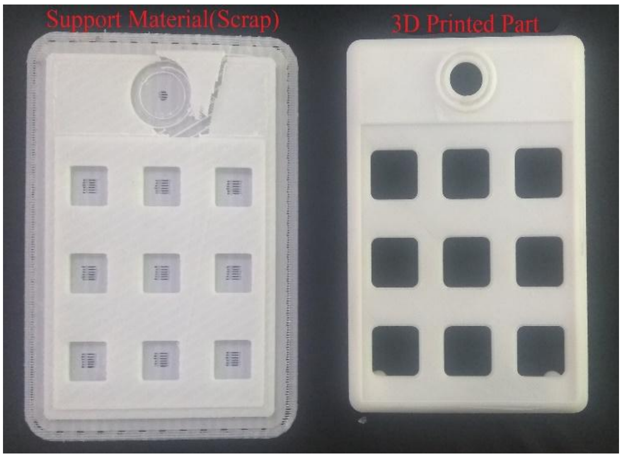

Figure 9 : Manufactured part in the FDM machine

As the part has been manufactured which can be seen in the figure 9 using Fusion Deposition Modeling (FDM) machine, as the material used to manufacture it was ABS which was feed in the form of extruded wire of diameter 1.5 mm, which is wound on a spool that is loaded to the machine. The support material should be provided to give support to the area which doesn’t have the basement to it, and also to prevent from getting damaged during removal.

IX. COST ANALYSIS

Direct material cost analysis of the metal air battery shell part for the original and the redesigned part is been shown in the Table 3

Table 3: Cost evaluation between the original and redesigned product

Part	Original Design Cost ₹	Redesign Cost ₹
Front Shell	250	250
Back Shell	200	200
Allen Screws	40	-
Cap	180	180
Total	**670**	**630**

The cost for the assembly of the metal air battery shell can be seen in Table 3 by which we can determine that the Allen head screws which have been used in the original design are eliminated. The time for assembly will also decrease as the time taken for the assembling of screws with the shells of metal air battery will be eliminated by which reduction of the manpower from the assembly line otherwise if same production is required from prior, design production cost would have been improved in mass production process.

X. RESULTS AND DISCUSSIONS

The main moto of the DFMA is to reduce the cost of product, by decreasing the production cost, the screws are been replaced with the cantilever snap fit and interference shaft fit respectively which will come inbuilt in the cap design and shell which makes the assembly simplified. Parts such as the shell i.e front and back shell including the cap which has been modified can be manufactured by minor modifications in the existing mould assembly. Cost of manufacture has a greater impact in the sales, so the cost optimization should be done by simplification of assembly by which cost of the assembly has been reduced by ₹ 40 which leads to a greater impact on the overall product cost. The Plastic Flow mould analysis results indicate that the mouldability of the part is good, complete filling of the mould taken as 10 seconds and the flaws in the mould have been analyzed proceeding to that the tonnage capacity of the machine required to manufacture the same parts with respect to the clamping force in ‘Y’ direction Vs the time of filling the mould cavity. Further to the testing of the product to be done as the product is of the plastic part the mould has to be manufactured which leads to a greater investment so the rapid prototyping has been employed in the manufacturing process by which the cost of manufacturing of single part is less as we are not manufacturing the Injection mould die unit, the parts resembles the same dimensions and aesthetic looks as such the injection molding process.

XI. CONCLUSSION

This paper address about the DFMA design procedure to design a metal air battery cell with optimum cost of manufacturing, step by step design stages are been described in this paper. Analysis results are been helpful in rectifying the cell design in the initial stages of design itself as any flaws has been analyzed in flow mould analysis.

Thus, DFMA guideline procedure has been followed to diminish the number of parts in the assembly which is termed as the simplification of assembly. The rejection rate during the manufacturing is eliminated which leads to decrease in the direct material cost of the product followed by which the rapid prototyping helps us to evaluate the product with minimum cost of production with less time to manufacture.

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Moin Ahmed Khan, is pursuing his M.Tech in Tool Engineering from RV College of Engineering®, Bengaluru. Prior to his master's degree he had an Industrial Experience in New Product Development (NPD) over three years, with a go-getter attitude and hands on experience in designing and development of functional machines. His areas of interest include NPD, Machine Design, Injection molding and Additive Manufacturing.

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Ankush Raina, has completed his bachelor's in Mechanical and Mater's in Materials Engineering from IISc Bengaluru and currently working as Design Associate at Log9 Materials Scientific Pvt. Ltd. Bengaluru. He is a designer who likes to work on various aspects of product design and development from functionality to aesthetics. He enjoys the process of exploring various concepts and bringing them to reality.