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HDPE As An Alternate Material for Metal Shroud Used in Screw Air Compressor Canopy: Analysis and Fabrication

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Abstract: ***Use of alternate material is always a continuous development in any industry. Such proposals aim at weight reduction, improve life of the components and reduce the components cost. When it comes to the compressor application, there is always a challenge in replacing such parts with polymers, especially on the canopy parts. This study aims at replacing the material of screw compressor canopy with a suitable material with the target of weight and cost reduction, without compromising the functional requirements. Suitable material for the shroud assembly is chosen using the theoretical method and validated using finite element analysis. Suitable process is chosen for the Proto-type shroud from the proposed alternate material (HDPE) and tested in the real-time environment***

Keywords**:** ***HDPE, Shroud, FEA, Screw air compressor, alternate material, canopy.***

I. INTRODUCTION

In any engineering industry, cost and performance of the product are the major criteria to have a healthy business. Such improved performances are derived by value engineering that includes, modifying material properties or choosing an equivalent alternate material. Such material property modifications are usually done either by altering the composition of the material or by subjecting the part for heat treatment to meet the specified functional requirement[1].This approach of modifying the material properties usually increases the cost the components, which may not be desirable in all applications. Use of alternate material may result in cost and weight reduction, which is always subjected to the specific application requirement.

Given the application requirement as weight and cost reduction of the metal shroud assembly used in screw air compressor canopy, suitable approach is to be chosen between modifying the property of the existing metal shroud or choosing an equivalent alternate material in replacing this material shroud.

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Since weight reduction is not possible by modifying the composition, selection of alternate light weight material is an appropriate method. Usage of polymers and composites as alternate materials is increasing and is expected to grow rapidly in future.

Patil, Patel, & Purohit, [2] refer in their works that automotive industry is very much supported by plastic industry which is now being extended to the structural design of the cars. Pantelakis, Katsiropoulos, Labeas, & Sibois, [3] has conducted his study on thermoplastic composite canopies for optimizing cost and quality, where in the material is changed from high-cost semi-crystalline thermoplastics, by lower performance/low cost semi-crystalline thermoplastics Similar work, Fuchs, Field, Roth, & Kirchain, 2008 [4] brief on the comparison of mild steel unibody compared with carbon fibre-reinforced polymer and the result is successful in weight reduction without compromising the functional requirement, also resulted in cost reduction. Saur, Fava, & Spatari, 2000[5], in their work analysed for four different material Steel sheet, Aluminium sheet, Sheet moulding component (SMC) and injection moulded polymer. Ashby, 2005,[7] has suggested the possible methods in the material selection for any given application, by converting the requirements in to an equivalent derivative. For computing thermal conductivity of particle reinforced epoxy composites, Ansys is used as the finite element analysis tool[8]. Work by Amir Bozorg-Haddad and Magued Iskander, 2011 [9] gives the relation between the life of the HDPE material subjected to creep.

In this case study, functional requirement of the shroud assembly, is analysed in identifying the suitable alternate material, with proto-type manufacturing and testing in meeting the requirement. Use of such alternate materials in automobile industry has been proven already which resulted in reduced weight and better fuel efficiency. Application of polymers in industrial requirement is increasing rapidly, because of its low weight to strength ratio, manufacturing convenience and cost.

A. Methodology

Below the methodology used in choosing and testing the alternate material for the application

1. Analysis of the existing shroud
2. Selection of alternate material for weight and cost reduction
3. Analysis for strength
4. Manufacturing process selection
5. Testing and conclusion

II. ANALYSIS OF THE SHROUD ASSEMBLY

A. Functional requirement

Functional requirement of the shroud assembly (item no 1) is to hold the cooler assembly (32 kg) (item no 2) and to withstand the fan (8 kg) (item no 3) at the bottom. The profile holds the specified volume of air and cools the cooler.
The volume and size of the shroud assembly is derived by the heat load requirement of the cooling system

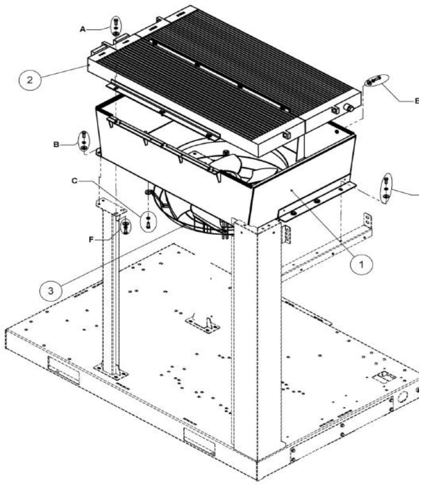

Fig 1. Shroud assembly

B. Current manufacturing process

Shroud assembly is currently manufactured with cold rolled sheet of 2 mm thick. And the sequence of the operations is cutting and punching to the required dimensions, Bending, welding, powder coating and assembly. Input material weight is 42 kg, and the total cost of the component is Rs 5096

C. Structural analysis of the current design

Since the load on the component is limited to tensile and compressive load, the study of the finite element analysis is limited to deformation. Original model is to analysis the current impact of the loads subjected. Assembly requirement of the shroud is then translated for the finite element analysis requirement Fan is mounted to the shroud assembly using fasteners at four equi-spaced provisions given in the shroud assembly. Similarly, cooler is placed over the shroud where the compressive load is transferred to the pillar assembly. Hence the compressive load acting on the cooler is exempted for the analysis. With the input as given below, finite element analysis is done for deformation and stress

Input for the structural analysis

1. Existing model
2. Young's modulus – 2e^{11} N/m^2
3. Poisson's ratio – 0.3

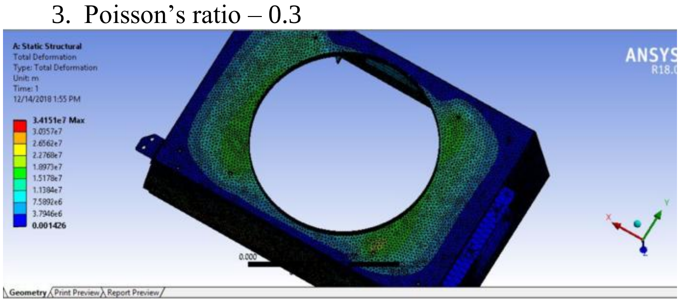

Fig 2 Analysis result

Structural analysis for the shroud assembly made of cold rolled sheet is carried out using finite element analysis and the output of structural analysis shows the deformation as 0.003mm, which confirms the existing DESIGN IS SAFE

III. ALTERNATE MATERIAL SELECTION

The objective is to choose the material that has the required strength in meeting the load condition aiming at low weight and cost by translating the design requirements. Suitable material is chosen using the theoretical methods referred [7]

A. Procedure for material selection

Material selection procedure starts with defining its function, constraint, objective, the free variable and other specific requirements

1) Function

As discussed earlier and with the current design set up the compression load of the cooler is taken by the pillar on which the shroud assembly is mounted and the fan mounted at the bottom of the shroud acts the tensile load.

2) Constraints

Dimensions of the current model is set as the constraint in deriving the new material to with stand the tensile load of 8 kg. Size of the shroud assy is set as the constraint - 1050 mm x 653 mm x 332 mm

3) Objective

The objective of the alternate material selection for the shroud assembly is defined as weight and cost reduction, without compensating the design requirements. Weight of the proposed shroud assembly shall be less than half of the current weight of 37 kg. Defining the requirement as equation,

$$m \leq A\ t\ \rho \qquad (1)$$

m- Mass of the component kg
A– Cross-sectional area mm^2
t - Thickness mm

4) Free variable

Free variables are the variables that doesn't restrict selection of material. In this application, thickness and material are the two free variables. Thickness of the material can be chosen based on the application requirement.

t – Thickness and the material mm

B. Deriving the material index

Steps in deriving the material indices (M) is given below

1. Selected material should with stand the tensile load generated out of the fan mounting, which is given by the equation

$$F / A \leq \sigma f \qquad (2)$$

where σf - Failure strength N/mm^2
F - Tensile load N
A - Area mm^2

2. By eliminating A in the equating equation (1) and equation (2)

$$m \geq (F)\ (t)\ (\rho / \sigma f) \qquad (3)$$

where m - mass of the component kg
ρ - density kg/m^3

This equation relates the impact of the density against the failure strength of the material chosen, independent of the load acting and the thickness.

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These independent variables ρ & σf are the criteria for the material selection and defined by the term Material index (specific strength)

where MI_1 - σf ⁄ ρ (4)

MI_1 – material index for cold rolled sheet

Current used material is cold rolled sheet with the properties as mentioned below.

Youngs modules E – 200 GPa

Density ρ – 7850 kg/m^3

Ultimate tensile strength σf – 350 MPa

MI_1- Material index for the current application, used with the cold rolled sheet is the specific strength which is defined by the equation 4

$$\text{Specific strength}_1 = \sigma f \,/\, \rho \quad (5)$$
$$= 350/7580$$
$$= 0.0445 \quad \text{MPa/kg/m}^3$$

Which has the material index for specific strength

$$\sigma f \,/\, \rho = 350/7850 = 0.0445$$

$$\text{Specific Modules}_1 = E/\rho \quad (6)$$
$$= 200 / 7850$$
$$= 0.0255 \text{ GPa/kg/m}^3$$

C. Selection of materials

Using the above 2 values Specific strength 0.0445 MPa/kg/m^3 in X axis and specific modules 0.0255 GPa/kg/m^3in Y axis in the below fig 3, the feasible list of materials for consideration are identified[6]

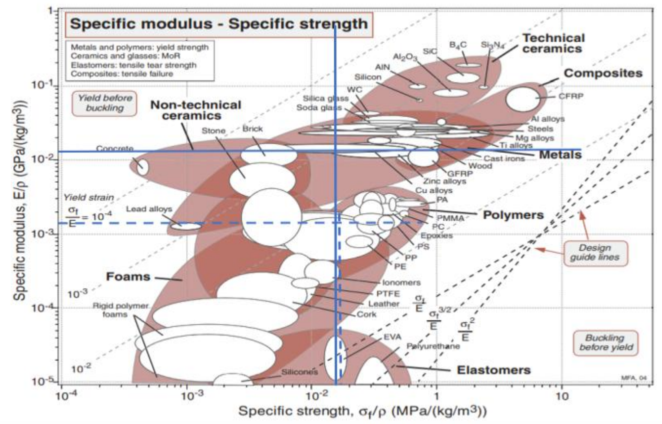

Fig 3 Selection chart – Specific strength vs. Specific modules [6]

Screening is the process, in which the possible materials that meet the selection criteria are considered for further functional requirements in terms of formability, aesthetics. Since the objective is weight reduction, we choose a material with better specific strength (greater than 0.0445 MPa/kg/m^3) from the above chart, we find many polymers fit to this requirement.

Since the objective is to reduce the weight, selection of materials should be less than the density of steel 7850 kg/m^3, means the selection should be on the left side of the highlighted blue line[6], also the current material meets the requirement, the young's modules (E) of the proposed material shall be less than or equal to the 200 GPa. Commercially available polymers which can cater to this application are liner low density polyethylene (LLDPE), High density polyethylene (HDPE), Acrylonitrile butadiene styrene (ABS). Selection of specific material among these will be based on the further analysis[9]

D. Design for manufacturing

Since the metal shroud designed for the fabrication process, the design is directly not suitable for manufacturing the part in polymers. Hence the re-design of the part is mandatory.

As we can see from the below two images, the strengthening ribs are removed and the thickness of the proposed shroud is increased. Provision for fastening the fan and cooler mounting are provided. With the revised design, shroud assembly directly assembles on the pillar and support bar, by eliminating the mounting pads, which provides more strength to the shroud assembly. 6mm thickness is proposed by considering the commercial availability (4mm, 6mm) of the standard sheets, which also supports in the factor of safety criteria

E. Input for analysis

As specified, the shroud assembly is mounted on the pillars on two corners and the support channel on the other side longitudinally. The functional requirement of the shroud is to hold the cooler assembly (32 kg) on top of shroud assembly and to withstand the tensile load of 8kg due to fan assembly at the bottom. High temperature gasket and sealing strip are fixed over the top of the shroud which take care of the heat transfer due to the oil temperature (90 deg C) inside the cooler. Cooler rests on this clip-on gasket and sealing tapes. Hence the analysis is limited [10]to the deformation of the polymer shroud due to the

(a) evenly distributed fan load acting on the mounting holes of the shroud

(b) compressor load acting on the top of the cooler

(c) above functional requirements along with the defined fixed support for the shroud mounting are the inputs for the analysis. Based on the deformation and stress analysis from the below 3 polymers, preferable one will be chosen for the part manufacturing HDPE – High density polyethylene, ABS- Acrylonitrile butadiene styrene, LLDPE – Linear low-density polyethylene.

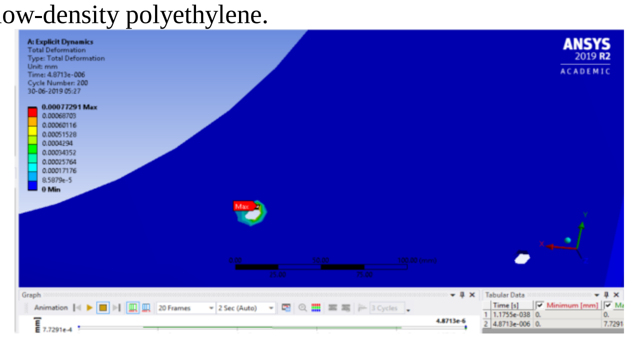

Fig 4 Deformation analysis of HDPE shroud

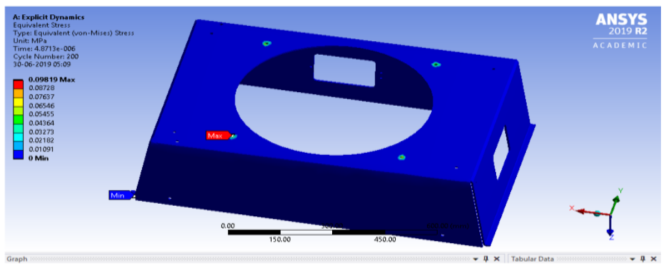

Fig 5 Stress analysis of HDPE shroud

Below the table I shows the property of different proposed polymers with the analysis results

Table I Mechanical property vs possible materials

	Property	Unit	HDPE	ABS	LLDPE
Material property	Young's Modules	MPa	1080	2390	368
	Poisson's Ratio		0.418	0.399	0.439
	Ultimate Tensile Strength	MPa	29.6	44.3	19
	Ultimate Yield Strength	MPa	25.7	41.4	13.6
	Density	kg/mm3	9.58E-07	1.04E-06	9.29E-07
Analysis result	Deformation	mm	0.0007	4E-04	0.0007
	Max Stress	MPa	0.0982	0.1	0.0989

IV. PART MANUFACTURING

Thermo forming is the process chosen for proto manufacturing because of the low cost involved in the tooling for the process, compared to Injection moulding and Roto moulding

A. Proto-type manufacturing

Tool is developed by duplicating the original shroud and using a 3 mm cold rolled sheet, and as per tool guidelines provided by the component manufacturer, which includes the strengthening of the tool across the corners to avoid deformation. Dimension control for the proposed shroud is provided in the tool itself.

Process parameters in developing the part in HDPE were not disclosed by the supplier. First sample manufactured has got failed, resulting crack and un-even thickness due to high temperature during the forming process. However, second sample manufactured met the specification

Fig 6 Image of the second sample (after post processing)

B. Qualification of the part

Part after manufacturing is compared for the specified dimensions. Since the part is the reflection of the tooling, no deviation found in the dimensions. Part is qualified for further testing

V. TEST, RESULTS AND DISCUSSION

At the part level, shroud made from metal is subjected only for the dimension for fitment requirement. Sealing for air leak between the shroud and cooler is done using the sealing tape and the clip-on gasket, after this assembly, the complete unit is tested for noise and vibration in the shroud area.

Below the parameters to be tested and compared for metal shroud and the specification

1. Deformation due to cooler and fan mounting
2. Vibration in the shroud during the fan running condition
3. Noise around shroud due to fan motor

A. Test set-up

Test set-up remains as per the original assembly requirement. For the modified design, (removal of stiffener's and mounting support), additional parts are manufactured to mount the cooler on the cross bar and the assembly is completed [11]

B. Noise test

Due to the change in material, noise test is conducted. This is as per the requirement of ISO 2151 – Noise test code for compressors and vacuum pumps, noise test is carried out as per the standards ISO3744 – Sound pressure-based Grade 2, following the ELGI test procedure. Bruel & Kjaer made Hand held Noise level analyser type 2270 is the instrument used for the noise test. Test is carried out for the entire compressor after the complete assembly to quality for the noise test clearance with the specification of 68(+3) dBA

Below the table II showing the noise result of HDPE made shroud and metal shroud compared with specification limit and found acceptable

Table: II Noise test result comparison

Shroud material	Measured value in dBA	Acceptable limit dBA	Result
HDPE made shroud	68.8	68(+3)	Accepted
Existing metal shroud	70.2	68(+3)	Accepted

C. Vibration test

Vibration test is conducted, as per the requirement of ISO 10816-3 any by following the ELGI test procedure. Vibration is measured on all the faces of the shroud in 3 directions, at the running condition. Vibration is measured for both HDPE and metal shroud in the same unit, without any other modifications.[12]

Since there is no exact specification for the vibration limit on the shroud assembly, referred for the maximum

allowable vibration on the rotating parts in the screw compressor as per the standard ISO 10816-3 and checked for this value – 10 mm/s and compared with the vibration value of the metal shroud. Maximum vibration shroud observed in the HDPE shroud is 3.4 mm/s whereas the vibration in metal shroud is 3.3 mm/s

D. Deformation test

Deformation test is carried out as per the assembly requirement by mounting the shroud over the pillar on one side and on the support bar on the other. Fan and cooler are assembled as per the requirement and the change in dimensions before and after this assembly is recorded. [13]

No deformation has been found during the testing under running condition. Deformation testing was conducted in the real time assembly and in the running condition to reach the maximum temperature in the cooler. This cycle is repeated for 15 times during the period, with the intention to expose the shroud to the different temperatures.

However, the maximum temperature of 90 Deg C inside the cooler will not affect the surface of the shroud, which was sealed with sealing strip and clip-on gasket. Also the work by Amir Bozorg-Haddad and Magued Iskander, 2011 [8] supports for the life of the HDPE under creep, will have the deformation of 2% by 100 years

Table 5.2 Variation in height during assembly

Height Specification mm	Height before assembly mm	Height after assembly mm	Height during loading mm	Result
304 +/- 1	302	302	0	Accepted
286 +/-1	284	284	0	Accepted

E. Analysis for weight and cost

Against the estimated weight of 14 kg, actual part weighted at 14.1 kg, is a reduction of 62% when compared to the original metal shroud. Actual part cost worked at Rs 3050, against the estimation of Rs 3200, which is a reduction of 40% when compared to the original metal shroud

Table 5.3 Cost and weight comparison table

Parameters	**Cold rolled steel sheet**	**HDPE (High density polyethylene) Actual**
Component weight kg	37	14.1
Total cost of the component Rs	5096	3050

Because of the selection of the low-density material as the alternate material for the application, weight of the shroud assembly is reduced from 37 kg to 14.1 kg. Thickness of the High density polyethylene sheet considered is 6 mm against the steel sheet of 2 mm. Considering the raw material cost and the manufacturing cost as Rs 220 / kg, estimation in-line with the current market rates, for the reduced weight of 14.1 kg, new cost estimated is Rs 3050 against the current operating cost of Rs 5096, which results the savings of Rs 2046

VI. CONCLUSION

Shroud assembly form electric powered screw compressor is taken for the study, with the intention to reduce the weight without compromising the strength

In the theoretical method, material selection is derived using the specific strength and specific modulus of the material. Feasible materials from the chosen group is then further subjected for the deformation and stress analysis using finite element analysis. Though the analysis results of the alternate material inferiors with the existing material (metal), still it meets the requirement. With these results and the feasibility for sample manufacturing HDPE material with 6 mm thickness is chosen.

As per the functional requirement, the HDPE shroud is subjected to noise test, vibration test and for deformation and compared with the metal shroud. This comparison suggests the chosen material meets the functional criteria which resulted in the weight and cost reduction as intended to improve the lifecycle cost of the compressor

VII. FUTUR WORK

Based on these results, the part is approved for mass production. The approach for the alternate material selection can be extended for similar applications, by defining its function, constraint, objective, the free variable and other specific requirements. This extension includes, when the part is subjected to different load conditions such as fatigue and creep, to understand the viscoelastic behavior of the part. The relation between the load on the shroud and the deformation can be formulated and can be extended for the exact similar application

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Dr. Sanjivi Arul completed his undergraduate degree in Mechanical Engineering from Coimbatore Institute of Technology, Coimbatore, affiliated to Madras University, India. He completed his Master's degree in Systems and Information from Birla Institute of Technology and Science, Pilani, Rajasthan, India. He earned his PhD from Amrita Vishwa Vidyapeetham, Coimbatore in the area of materials science. Presently he is an Associate Professor in the Department of Mechanical Engineering, Amrita School of Engineering, at Amrita Vishwa Vidyapeetham, Coimbatore, India. His research interests are Surface Alloying, Cryogenic Materials Processing, Materials Development, Welding, Modelling and Simulation. He has published thirty nine Scopus indexed articles.

K Suresh Karthikeyan, with 15 years of experience in developing various types of engineering components with suitable suppliers locally and abroad. Currently working for an original equipment manufacturing company located in Coimbatore, which has its presence in 100 countries. Commodities handled includes, fabrication, casting, machining, etc., where the responsibility is to deliver the parts to the project on time with the estimated price and in meeting the product quality. He has completed his M.Tech in manufacturing management from Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, 2019. Earlier he also completed is Master of Science in Manufacturing management from Birla Institute of Technology and Science, Pilani, Rajastan.

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