Optimum Material and Process Modification to Reduce Lead Time of Pedestal Manufacturing Used in Gearbox Assembly

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***Abstract* - In recent years computer aided engineering techniques has developed to great extent, the choosing right materials and processes are great challenge for the engineers. This paper discusses about material and process selection based on computer aided technique. The output from all CAE tools is based on the accuracy of the provided input, therefore the requirement for using this tool is to understand the behaviour of the product and to specify the appropriate input. The CAE Techniques provides better understanding of the processes and material selection and helps to modify the products as it is essential to compitate in today's global market. The one such software is CES, (Cambridge Engineering Selector) which is used to modify the material selection and manufacturing processes used for the pedestal of the gearbox without affecting the functional requirements. This paper illustrates various consideration made for modification and the material and process of pedestal. The performance of the existing material and modified material is evaluated using finite element analysis and comparison of result is shown.**

Keywords: Material selection Parameters, Material selection for Gearbox, Material selection using CES software & Finite Element Analysis.

1. INTRODUCTION

Material science and manufacturing technology has witnessed large scale development in recent years, providing the design engineer with large choice of novel materials and processes to engineer from. This also calls for informed decisions in the choice of materials for engineering application design failing which can lead to flaws in modulus, strength, toughness, cost etc. In architectural sciences, Pedestal's have been used since the time of the Romans for architectural work in temples, followed by Italians and Chinese to support the statues and position the statue at particular heights.[1] In engineering sciences Pedestals have been designed to form the supporting elements of gearboxes, motor and as a means to hold measuring tools within a framework of machine design. In later stage the word is commonly used for all supporting element, as in gear box assembly, the gearbox is supported and raised by this element therefore this is named as pedestal.[2] The pedestals are also used in rolling machines for fixing the machine. [3] This often calls for the structure of the pedestal to be rigid, however, most often existing pedestal designs are manufactured with six parts welded together, which involves cutting to required shape and machining to the dimensions, welding, stress reliving, inspection etc shown in Figure 1. The lead time for processing of pedestal is high, therefore in order to reduce the lead time, alternate material identification and process optimization is discussed in this paper.

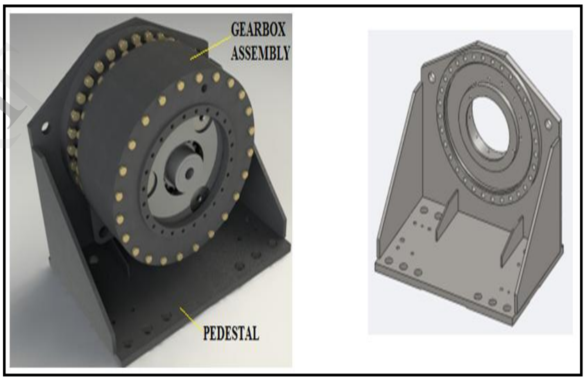

Figure 1 Pedestal with gearbox assembly

The various considerations have to be made while selecting the raw material and processes shown in (Figure 2). To select a material or process the following constrains also needs to be satisfied, only the major criteria are criteria is listed apart from this based on application of the product some other criteria may be must for material and process selection. This can be arrived only by systematic study to understand the behaviour of the product. The very precise input is required to apply constrains in CES software in order to select very precise materials

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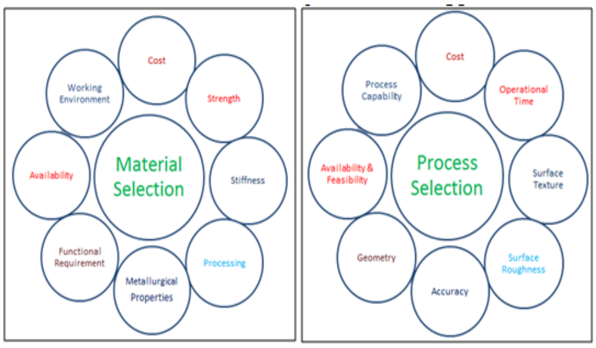

Figure 2 Material and processSelection Considerations

2. ANALYSIS OF ALTERNATIVE MATERIALS AND PROCESSES FOR PEDESTAL MANUFACTURING [4]

Materials selection charts are a graphical way of presenting material property data in a systematic arrangement. Most mechanical characteristics extend over several orders of magnitude, so logarithmic scales are used to array the materials as per the properties from low to high.

In order to select the suitable material the performance index is derived for the pedestal component. The performance index is the function of following parameters, functional requirements, geometry parameters and material properties [4]

$$P = f\{F, G, M\}$$

Were, P = Performances (mass, volume, cost, etc.)
F = Functional requirements
G = Geometric parameters
M = Material properties

The objective arrived for pedestal is

$$m = AL\rho$$

Were, m= mass, A= Area, l = Length and ρ= Density. The defined objective are mass depends on volume and density, which has to be less and the constrains focused are,

$$F/A < \sigma_y$$

Were, F= force, A= Area and σ_y = yield strength of material. This defines that the stress levels should be always below the yield strength of the material, this constrain ensures the material is in elastic limits and only elastic deformation takes place for the applied load. The equation is re-arranged to eliminate the free elements as

$$m \geq (F)(L)(\rho/\ \sigma_y)$$

The weight can be minimised or increased using the variables density and yield strength. In order to arrive at the materials with light weight yet with high stiffness the performance indices are arrived to materials as

$$P = \sqrt{\frac{E}{\rho}}$$

Were, E = Young's modus
ρ = Density of material

In log space: log E = 2 (log ρ + log M) this is a set of lines with slope=2

Young's modulus is the measure of stiffness in a material. As per Hook's law within the elastic limit stress (σ_x) is directly proportional to strain (ε_x) the constant proportionality (E) is called Young's modulus.

$$\sigma_x = E\,\varepsilon_x$$

Michael Ashby of Cambridge University has developed the material plot graph, displaying two or more properties of material together that enables the user to select the appropriate material. The CES software functions using the Ashbey's plot. The CES [5] software has the material database in which level-2 with eco and durable property database is selected for analysis having 98 materials under different families.

In order to select the material with qualities of low weight and high stiffness using CES software the material of all the families are plotted in graph stage for density to Young's modulus and the slope will be 2 has to be generated as shown in Figure 3. The material falls below the line of the slope are suitable materials and can be taken forward for further refinement.

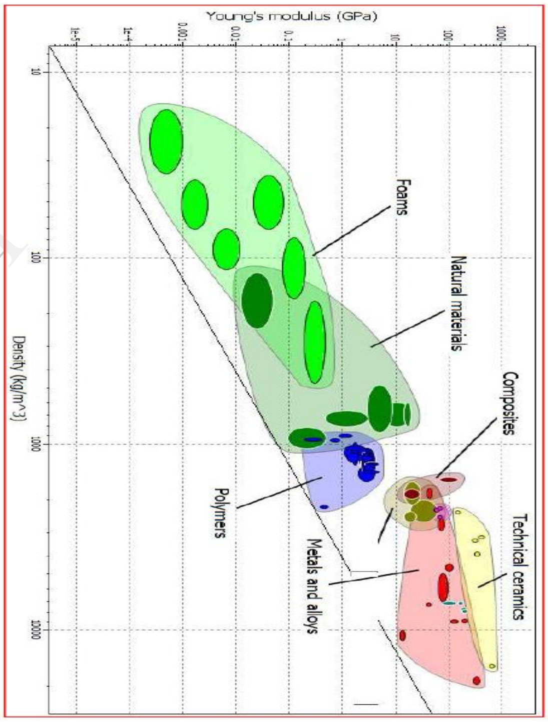

Figure 3 Young's modulus Vs Density graph

The various family of materials carried forward for refinement are Foams, Natural materials, composites, polymers, metals and alloys. The suitable constrains are applied by considering the functional requirements. By adding constrains in the graph stage such that the material should have minimum Young's modulus value of 100GPa. The materials are refined and were end up with 3 family of materials with 17 material candidates as shown in the Figure 4.

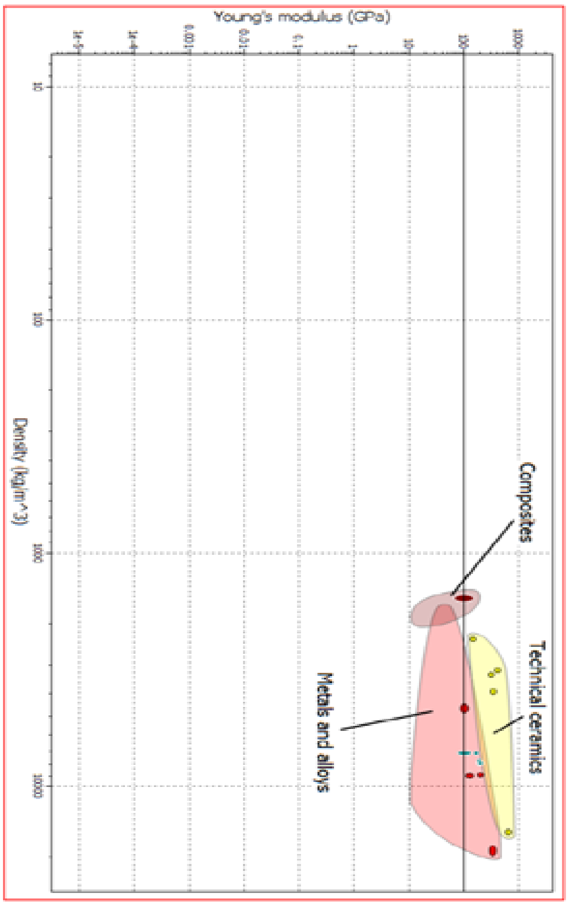

Figure 4 Young's modulus vs density graph with 100GPa constrain.

For the further refining, constrain given in CES software in limit stage. The limit stage helps to set the upper and lower limit in order set constrain. In this stage for Young's modulus the limit of 180GPa to 230GPa is set in order to further refinement.

Application of this constrain to the list of materials results in filtering of materials such as ductile cast iron, low alloy steel, low carbon steel, medium carbon steel, nickel, nickel based super alloy, nickel chromium alloy, stainless steel and zirconium. For the further refinement of material the graph plotted for the castability and the yield strength as shown below in the Figure 5. The result shows the ductile cast iron has higher castability and the range of the yield strength is also similar but slightly less than the low carbon steel.

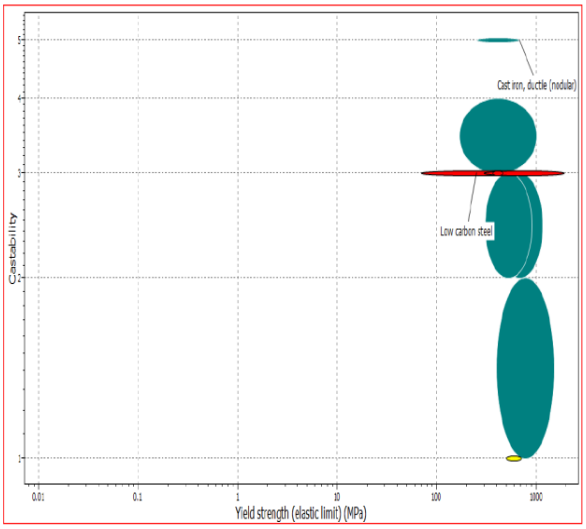

Figure 5 Castability Vs Young's modulus graph

As the pedestal manufacturing process involves various machining processes such as drilling for clamping holes and jig boring to fit bearing for output shaft, the machinability is the important property required for the component and therefore the graph of machinability and compression strength is plotted and shown in Figure 6.

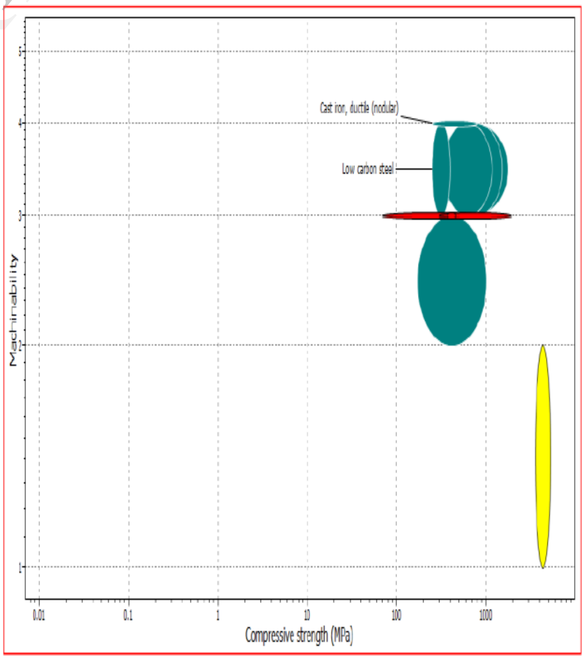

Figure 6 Machinability Vs Compressive strength graph

For the further refinement as the pedestal has to hold the total weight of the gearbox it is subjected to tensile loads and therefore the graph of tensile strength in MPa is placed the result shows the ductile cast iron has higher tensile strength than the low carbon steel as shown in Figure 7.

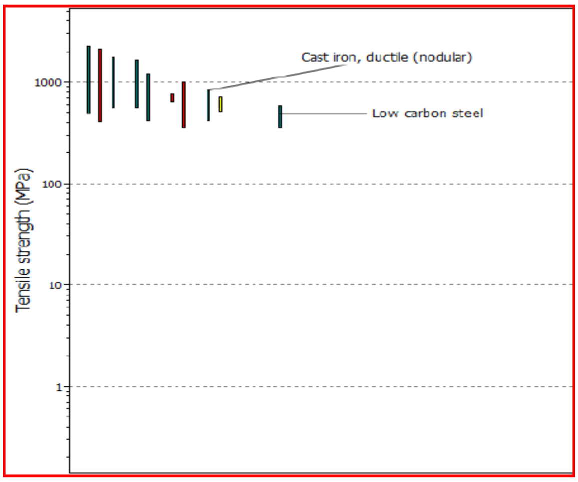

Figure 7 Tensile strength graph

As the structure of pedestal should be stiffer and stronger, the preferred material is ductile (nodular) cast iron as the material is suitable for bending and torsion loads were gray cast iron is not preferred. [6]

The comparison shown for the properties of ductile (nodular) cast iron and low carbon steel in order to get an idea of the various parameters required for the pedestal is met to modify the material taken from the CES 2009 software database shown in Figure 8[5].

General properties	Ductile(Nodular) cast iron		Low Carbon steel	
Density	7.05e3 - 7.25e3	kg/m^3	7.8e3 - 7.9e3	kg/m^3
Price	* 27.6 - 30.4	INR/kg	* 31.5 - 34.7	INR/kg
Mechanical properties				
Young's modulus	165 - 180	GPa	200 - 215	GPa
Shear modulus	64 - 71	GPa	79 - 84	GPa
Bulk modulus	119 - 137	GPa	158 - 175	GPa
Poisson's ratio	0.26 - 0.28		0.285 - 0.295	
Yield strength (elastic limit)	250 - 680	MPa	250 - 395	MPa
Tensile strength	410 - 830	MPa	345 - 580	MPa
Compressive strength	250 - 790	MPa	250 - 395	MPa
Elongation	3 - 18	%	26 - 47	%
Hardness - Vickers	115 - 320	HV	108 - 173	HV
Fatigue strength at 10^7 cycles	180 - 330	MPa	* 203 - 293	MPa
Fracture toughness	22 - 54	MPa.m^1/2	* 41 - 82	MPa.m^1/2
Mechanical loss coefficient (tan delta)	0.002 - 0.009		* 8.9e-4 - 0.00142	
Thermal properties				
Melting point	1.13e3 - 1.25e3	°C	1.48e3 - 1.53e3	°C
Maximum service temperature	350 - 450	°C	* 350 - 400	°C
Minimum service temperature	-98.2 - -38.2	°C	* -68.2 - -38.2	°C
Thermal conductor or insulator?	Good conductor		Good conductor	
Thermal conductivity	29 - 44	W/m.K	49 - 54	W/m.K
Specific heat capacity	460 - 495	J/kg.K	460 - 505	J/kg.K
Thermal expansion coefficient	10 - 12.5	µstrain/°C	11.5 - 13	µstrain/°C

Figure 8 Ductile cast iron and low carbon steel comparison

The comparison of the low carbon steel material and ductile cast iron material shown in Figure 8. It can be observed that the Young's modulus value is lesser for the ductile cast iron 15% lesser than low carbon steel but the rest of the properties like elastic limit, tensile and compression strength of the material is much better than the low carbon steel. According to the Dandong Foundry, China [7] in gray cast the presence of graphite will be in the form of flakes due to this it has lower strength and it is used to produce the components such as used machine bases, housings etc. were the component is subject to less load. And in ductile cast iron the graphite is present in the form of spherical shape due to this it can withstand high tensile and compressive loads and used to produce components such as brackets, crankshafts, connecting rods etc.

For eliminating the gray cast iron from the material candidate the further comparison is made between the gray cast iron and ductile cast iron material properties as shown in Figure 9. According to the Sumitomo drive technologies [8][9] in Cast iron Vs ductile iron housing materials topic has quoted *"Ductile iron is typically twice as strong as many grey cast irons, and nearly as strong as steel"* and shown the table comparing the gray cast iron and ductile iron shown below:

Material	Properties	Strengths	Weakness
Cast Iron	Tensile FC200 ≥ 200 N/mm² [29,008psi] FC250 ≥ 250 N/mm² [36,259psi] A48 No.35 ≥ 35,000psi [241 N/mm²] A48 No.40 ≥ 40,000psi [275 N/mm²]	▪ High Strength/Weight ▪ Low Production Cost ▪ High Machinability ▪ Vibration Dampening ▪ Excellent up to moderate shock loading ▪ Superior compressive strength compared to steel	▪ Lower tensile strength compared to steel ▪ More brittle compared to ductile or steel when used for shock loaded applications ▪ Temperatures below 30°F/0°C are susceptible to thermal/impact shock and brittle failure.
Ductile Iron	Tensile FCD450 ≥ 450 N/mm² [65,260 psi] A536 65-45-12 ≥ 65,000psi [448 N/mm²] Yield FCD450 ≥ 280 N/mm² [40,610 psi] A536 65-45-12 ≥ 45,000psi [310 N/mm²] Elongation FCD450-10 > 10% A536 65-45-12 > 12%	▪ High Fracture Toughness (Ability to resist fracturing) when compared to cast iron) ▪ High Fatigue Strength compared to cast iron ▪ High Machinability ▪ Vibration Dampening ▪ Excellent for shock and impact loading ▪ Similar casting/pouring properties to cast iron ▪ Excellent cost / ratings improvement	▪ Slightly higher coefficient of expansion than cast iron. ▪ Slightly lower machinability compared to cast iron. ▪ Only slightly higher brittleness from cast iron below -25°C (-13°F)

Figure 9 Cast iron and Ductile iron comparison

In order to ensure the functionality of pedestal, finite element analysis is conducted for pedestal with same load and boundary conditions, by applying the properties of low carbon steel and ductile iron. The deformation and stress results are compared.

3. FINITE ELEMENT ANALYSIS [10]:

Finite Element Analysis is an engineering analysis technique which is widely used in various field of engineering, implemented to identify behaviour of complex structures for which no exact solutions exist. The basic concept of finite element analysis is to convert the complex problem into a simple form by descretised into many small parts called elements, each elements has nodes which has degree of freedom and it enables to solve the complex problem easily, by finding the solution to all small parts and the sum of behaviours of all parts are assembled into one solution for the overall problem.

3.1 Mesh Generation and Elements:

The meshed model is generated using Hyper Mesh 2009 software, in order provide appropriate loads and boundary conditions the whole mass of the gearbox assembly is idealized as a mass node at the center of mass position as per Saint Venant's principle. [11] The elements used in meshing are 3D elements (Solid92-3D 10-Node Tetrahedral) the 1D element (Mass 21) and 2D elements (CERIG) rigid elements connecting mass node with solid elements are used in Finite element modelling as shown in Figure 10

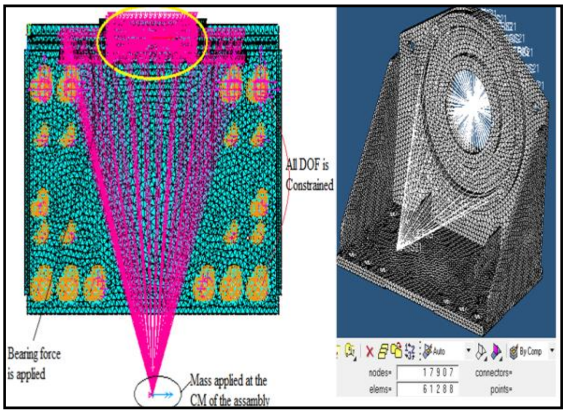

Figure 10 Meshing and Idealization

3.2 Displacement Result Comparison

The finite element analysis involves three stages; pre processing involves creation of finite element model, Processing involves matrix generation, solving and evaluating the result. The post processing involves viewing of deformation, stress results. The deformation in the pedestal with plain carbon steel material is 0. 12 mm and deformation in ductile iron is 0.014 the Young's modulus considered for plain carbon steel is 210 GPa and for ductile iron is 180GPa as properties obtained from CES shown in Figure 6. This shows the percentage of difference in Young's modulus for plain carbon steel to ductile iron is 15%. The percentage of difference in deformation for plain carbon steel pedestal to ductile iron pedestal is 15%. This is due to the material is considered to homogeneous isotropic and therefore it obeys Hook's law. From the comparison of result it was concluded that by changing plain carbon steel material to ductile iron the deformation will be increased by 15%, if that is acceptable than the material and process can be modified.

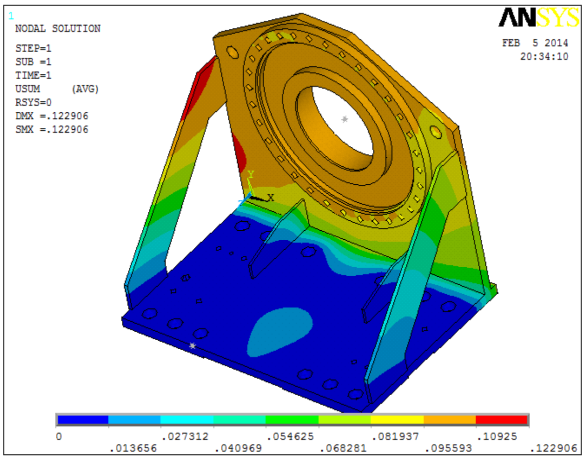

Figure 11 Deformation result of pedestal with Plain Carbon Steel

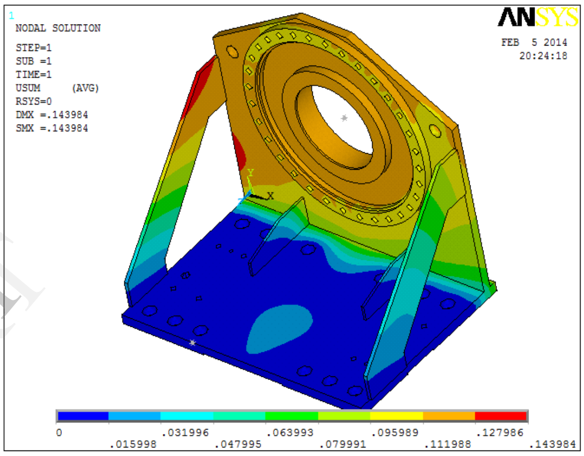

Figure 12 Deformation result of pedestal with Ductile Iron

3.3 von-Mises Result Comparison

The von- Mises stress criteria is also termed as distortion energy criteria for predicting the failures in theories of failures, widely used criteria as it predicts the failure accurately for metals and alloys which are ductile in nature. As per this criteria when the stress is equal to or greater than the distortion energy the material fails. [12]

$$\sigma_v = \frac{\sqrt{(\sigma_a - \sigma_b)^2 + (\sigma_b - \sigma_c)^2 + (\sigma_c - \sigma_a)^2}}{2} \leq \sigma_y$$

Where, σ_v = von-Mises stress criteria, σ_a, σ_b and σ_v = Principle stress and σ_y = yield strength of material. As per von-Mises stress criteria the maximum stress in plain carbon steel is 139 MPa and 137 MPa therefore in the both the cases the pedestal is in elastic limit and only temporary deformation will take place.

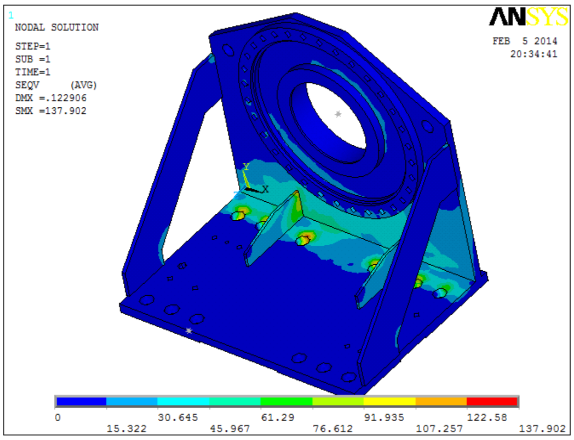

Figure 13 von-Mises Stress result of pedestal with Plain Carbon Steel Material

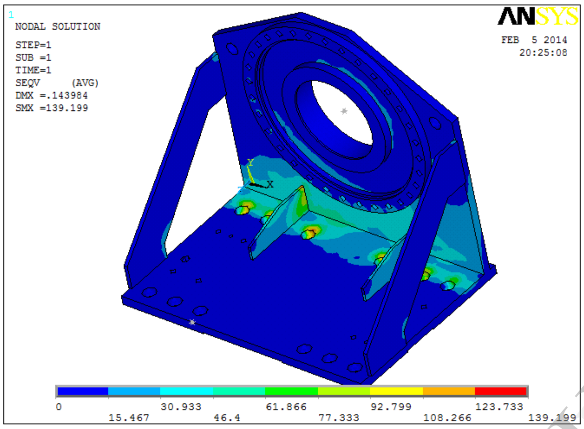

Figure 14 von-Mises Stress result of pedestal with Ductile Iron Material

4. CONCLUSION AND RECOMMENDATIONS:

By the analysis conducted on pedestal the suitable material recommended is ductile iron and the suitable process recommended is sand casting processes.

The benefits of recommendations are:

- Pre machining of low carbon steel plates can be totally eliminated.
- Welding operation is eliminated
- Stress reliving operation is eliminated.
- Assembling and inspection operation is eliminated.
- Reduced machining time
- The deformation can be further reduced by adding stiffeners as the casting provides shape flexibility.
- By conducting topology optimization analysis optimal shape can be arrived with less weight in pedestal as shape freedom is there in casting process.

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