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Research Paper

Design and Static Analysis of E-Glass/Polyester Composite Mono-leaf Spring

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ABSTRACT: *In this paper, the design and Static analysis of EGP mono leaf Spring for KIA- K2700 mini truck model made from E-glass/Polyester composite materials presented. An electrical glass/polyester composite laminated mono-leaf spring prepared in three plates of three different standards of center ply matrix configuration corresponding to suggested matrix contribution of the volume in customized geometry design matching for KIA truck model K2700 taking an specified static load of 5.252 KN in to consideration and material properties such as flexural and tensile strengths and impact energy absorption characterized with relevant tests. According to the static analysis results, the study revealed that EGP mono leaf spring ensures better performance than that of the conventional steel leaf spring of KIA k2700 mini truck model. Nevertheless, type-A matrix demonstrated higher tensile/impact strength whereas type-C shown superior flexural but reduced impact strength relatively.*

KEYWORDS: *Finite Element Analysis, Mono leaf spring, multi-leaf spring, E-glass polyester composite, Impact strength, composite synthesis, Flexural Strength. Tensile Strenght*

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I. INTRODUCTION

Composite materials were made possible to reduce the weight of the leaf spring without any considerable sacrifice on load carrying capacity and stiffness of the mechanical system (the suspension spring). An induced stress 74.58% and deformation 68.29% achieved by using carbon/epoxy composite mono leaf spring instead of conventional steel leaf spring under the same loading condition with 76.85 weight reduction according to ansys analysis which was promising (Abebaw, 2017). In an attempt to improve strength to weight ratio, static analysis and prototyping of single composite leaf spring for light vehicle exhibit acceptable fatigue life of 221.16*103 cycles with stresses much below strength properties of the material (Gebremeskel, 2012). Non-linear static analysis of 50 car rear leaf steel springs and E-glass/epoxy composite leaf spring found that 52.65% less stress and 49.43 higher stiffness than the conventional multi-leaf steel leaf spring. Reduced thickness from 9.25mm to 8mm at standard deflection shown stress difference of 29.98% and stiffness 12.95%. Design optimization yielded 76% weight reduction (Ashok Kumar & Kalam SD, 2016; Islam, 2019). Fibre Reinforced Plastic (FRP) composite helical composite recently seen gradually replacing steels due to its light weight, high modulus/strength, strong anti-chemical capability, high degree of freedom for design and process ability in Rapid Application Development (RAD) of automobile parts (Balaguru, Anbu, Bhuvanesh, & Jayanth, 2016).

K2700 is 5,125x1,740x 1,970 mm^3 1.5 tone standard cabin truck with mixing load carrying capacity of 1.3 tone. Multi-leaves spring suspension of quenched and hardened high carbon steel (7,840 kg/m^3 density, 210GPa modulus and 0.29 poison ratio) is used to isolate the system from shock. There are 2 full-length springs, 3 graduated leaf springs and number of total laminated springs is 5. The width, thickness and eye-to-eye (2L) of leaf are 60, 8 and 860 mms respectively. The first and second leaves are full length 860mm, whereas third, fourth and last leaves are 820, 740 and 700 mms respectively. Bore and outer diameters of eye are 24mm and 40 mm respectively. Camber under no load condition is 77cm (KIA mini truck model broacher).

This paper is constitute three different approaches to fulfil the initiated objectives. The first part is determination of stress induced in multi-leaf spring at fraction of static loading condition on particular wheel and associated deflection with SUP7 material. Subsequently, composite fabrication and testing report presented where an E-Glass/Polyester composite material in one of three different synthesis standard (type C mold because of its low density) prepared and tested for tensile, flexural (bending), and impact by UTM and Cahry Impact Test apparatuses with standard specimen prepared from all three fabricated samples (to accommodate testing error) with standard size as well as shape requirements and procedures of experiments. The test results are used to analytically determine size (width and thickness) of EGP mono leaf spring to carry the load specified and calculated by the first step. It is followed by maximum deflection calculation and weight determination are followed. Eventually, static analysis and simulation conducted using ABAQUS and results are compared. Earlier to this, the model prepared both for multi-leaf spring and EGP mono-leaf spring with the specified dimensions aforementioned using SOLIDWORKS 2016.

II. DESIGN CONSIDERATION

Static load derived first from gross vehicle mass (GVM)-sum of curb weight and load carrying capacity multiplied by safety factor. Weight $w = GVM * g$, where $GVM = (155kg + 1300kg)x9.81\, m/s^2) = 4{,}282.5kg$. $W = GVMxg$, W=4,282.5*9.81m/s^2=42kN.

Assuming level parking, each wheel carries quarter of weight. 10.502.5kN. Considering two hinges supporting multi-leaf spring as shown in 2D geometry taking equilibrium in diagram 1 in to account, right hinge/support (randomly selected for the design consideration) must carry half of the load at the wheel (GUPTA, 2005). F=5252N.

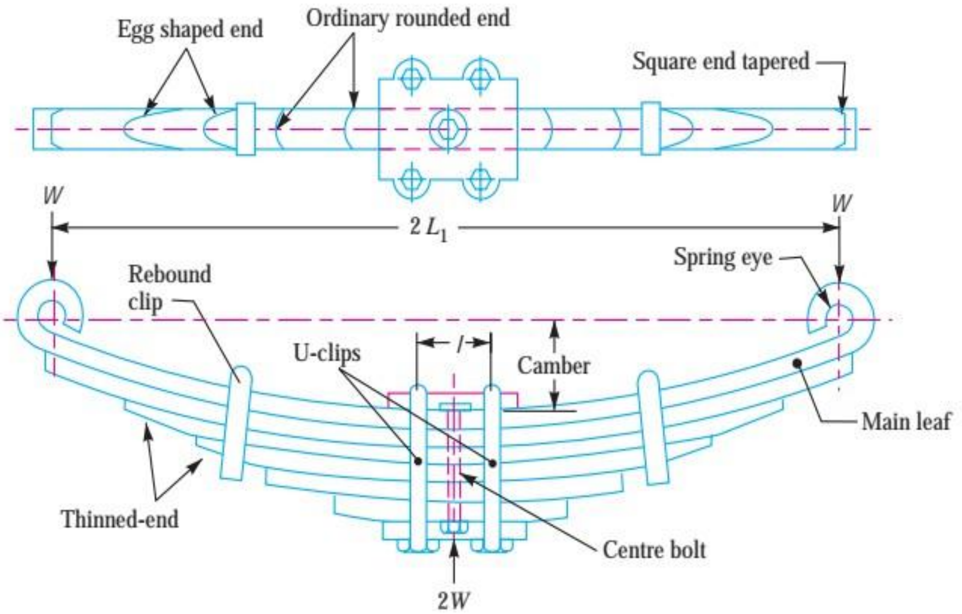

Diagram 1

Maximum bending stress induced in the rectangular multi leaf spring plate if given by equation-1:

$$\sigma_b = \frac{FL}{nbt^2} \quad \rightarrow 1$$

. Where F is load at hinge, L is half eye-to-eye span (but band-Lb is subtracted as shown in equation-2 from the total span because only effective length portion of the span involve bearing the load), n-number of leaves, b width and t-thickness.

In ordered to determine effective length leaf spring (2Le), the following geometric analysis employed. 2Le=2L1−Lb. Equivalent equation for effective length when U bolt band used becomes

$$2\text{Le} = 2\text{L1} - \frac{2}{3}Lu \rightarrow 2$$

Where: 2Le = effective length leaf spring, 2L1 = total length of the master (full length) leaf spring Lb, Lu = length of band or U – bolts. But for this design U-bolt is used as fastening mechanism of the leaf spring on the axle of the vehicle.

Therefore, this equation yields: 2Le=2L1−2/3lu, take the width of the U-bolts = 54 mm (direct measuring from KIA- K2700 Mini-truck.) 2Le=860mm -2/3* 54mm = 824 mm. Le = 412 mm, (half effective length of current steel leaf spring). With all data known so far, $\sigma_b = 676MPa$.

Strain energy absorbed by SUP7 multi-leaf spring can be determined by equation 2

$$u = \frac{\sigma^2}{\rho E} \rightarrow 3$$

. With data from manufacturer's broacher and stress calculated above, it is determined 303 J/kg. Maximum deflection can also determined by an equation3:

$$\delta_{max} = \frac{4FL^3}{Enbt^3} \rightarrow 4$$

δ_{max}=4*5252N*(412mm)^3/[210*109N/m^2*5*60mm*(8mm)^3]=45.54mm

Eventually, the weight of SUP7 multi leaf spring is calculated by summing up all five leaf springs attached to K2700 mini truck 2016 model truck one wheel using equation 5.

$$W = \rho x V * g \rightarrow 5$$

Now L1=L2=860mm, L3=820mm, L4=740mm and L5=700mm and weight of the master leaf (W1) = ρ×V1×g =W2. Where, acceleration due to gravity (g) = 9.81 m/s2; V1 = L1×b×t and L1= length of full-length springs or length of master leaf spring t= thickness of the leaf spring=8mm and b= width of the leaf spring=60mm (all data taken from manufacturer broacher). Consequently, V1 = volume of master leaf spring= 860 mm × 8mm × 60 mm= 412.8 cm3

W1 = 7.86 gm/cm3 × 412.8 cm3 × 9.81 m/s2 = 31.83 N

Similarly, (W2 = W1) = 31.83 N; considering graduated leaves, weight of 3rd leaf (W3) = 30.35 N; Weight of 4th leaf (W4) = 27.38 N and Weight of 5th leaf (W5) = 25.91 N

Therefore, the total weight of the current existing SUP7steel leaf spring of the KIA- K2700 model mini truck vehicle becomes WT = 2W1 + W3 +W4 + W5 =147.299 N

III. MATERIAL SELECTION, AND COMPOSITE MOLD DEVELOPMENT

E- Glass/C-glass fiber materials provided by Ethiopian Plastic Industry Workshop which is available with the following fiber matrix available in various lengths with w x t dimensions 200 nm x 0.8 mm. E-Glass fiber selected for its superior mechanical strength, great wet-through and fast wet-out in resins, rapid air lease, good compatibility with polyester and low cost making it viable option (JUSHI, n.d.).

It is prepared in chopped strands to make P04 E-Glass (0.85nm) for use in hand lay-up, filament winding, compression molding and continuous laminating processes. Polyester used as binding-agent/catalyst to hold together for its ease of handling, economical (low cost), dimensional stability and good mechanical/chemical resistance. Methyl ethyl ketone peroxide hardener and wax release agent applied. In other words, General purpose Polyester resin, mixed with hardener of Methyl Ethyl Ketone Peroxide (MEKP) is used to prepare the composite plate. The weight (Mass) ratio for mixing POLYESTER and HARDENER is 100:10 (Al-bayati, 2016).

Standard geometry of mold comprise 5mm±0.5mm thickness, 300mm by 300mm overall width made considering cutting/manufacturing error allowance.

Lists of materials used in the hand lay-up technique are: 1. 300 mm *300 mm glass based and wooden frame mold area, 2. 4 iron blocks weighing a total of 100kg for pressing purpose, 3. ¾ inches brush, 4. Stirring stick and plastic bowl, 5. Mold release chemical and 6. Safety apparatus (hand gloves, eyeglasses, mouth cover, safety shoes (Patel, 2017)

'Rule of Mixture' by mass/weight fraction constituents of manufacturer's data along with standard research suggestion deliberated to determine mixture proportion (Reddy, 2017). Weight fraction of fiber W_{ff} and weight fraction of matrix W_{fm} can be determined from weight of fiber W_f and weight of composite W_c according to equation 6, 7 and 8. Introducing common denominator W_c to equation 6 and substituting equation 7 and 8 to 6 yields equation 9. The expression can be presented in terms of volume fraction and density which is reduced to avoid redundancy.

$$W_f + W_m = W_c \rightarrow 6$$

$$W_{ff} = \frac{W_f}{W_c} \rightarrow 7$$

$$W_{fm} = \frac{W_f}{W_c} \rightarrow 8$$

$$\frac{W_f}{W_c} + \frac{W_f}{W_c} = \frac{W_c}{W_c}$$

$$\frac{W_f}{W_c} + \frac{W_f}{W_c} = 1 \rightarrow 9$$

According to (Al-bayati, 2016), fiber orientation has its own impact on the required mechanical and physical properties of the composite material to be produced. Hence, in this work, 3 variations are implemented to produce the required composite mold. Given density of E-Glass fiber and polyester resin 2.58 gm/cm3 and 1.07 gm/cm3,

Table 1 Mold variations based on fiber type and composition ratio (F: R) where PC is powder chopped glass fiber in to stranded 0.85mm thick fiber, EC-Emulsion chopped in 0.415mm thick, and WC-woven chopped in 0.85 mm cross linked fiber

Mold Name	Fiber Orientation sequence	Center Ply	L x W x t all in mm	Volume In mm3	Mass in grams	Density in gm/cm3	ratio(F:R), by mass %
A	EC:EC: WR: PC: WR:EC:EC	PC	340x280x5.5	523.6 cm3	880	1.681	32.95
B	EC:EC: PC: WR: PC:EC:EC	WR	343x293x5.5	552.74	960	1.736	35.42
C	PC:EC: PC:EC: PC:EC: PC	EC	345x290x5.5		870	1.5815	44.50

Mechanical testing Conducted on all specimens types: Mold Plate Type A, B and C. In order to sequentially stack mixture and produce composite mold, the mixer is strewed with stirrer for about 40 seconds continuously. The mixing is performed in the mixing containers (Bowl). The bowl is made up of transparent glass to prevent melting of the Bowl during the exothermic reaction. Mixing done slowly not to entrain any excess air bubbles in the resin. Finally, after full mixing of the resin and hardener, it changes to blue color (Yazachew, 2018).

Hand lay-up technique is used to produce composite plate because of ease of composite processing. The infrastructural requirement for this method is also minimal. First, a releasing agent is sprayed on the surface of mold to avoid the sticking of polymer to the surface. To get good surface finish of product, thin plastic sheets are used at top and bottom of mold.

IV. MECHANICAL EXPERIMENT

For each of three mechanical test experiments, three identical specimens prepared in sub total of nine samples in each three types of Mold Plate (A,B and C) in order to accommodate experimental error allowances so that average measurements used for the subsequent analysis. The total number of specimens/samples prepared was 27 for all mechanical testing. The first test is fluxural strength test using PT-WOW 100 computer controlled servo hydraulic universal testing machine with ISO 14125-1998 (E) specimen standard. Three identical samples with dimension in mm: L x b x t of 200x15*5 prepared and average values considered. It is followed by tensile strength test with three identical sample with size in mm: 120x15x(15x5$\pm$0.5) with gauge length of 60 mm according to aforementioned UTM standard. Finally impact energy absorption test experimented using standard speciment size in mm of 80x10x5 according to standards of JBS-500B Chahrpy impact test apparatus.

Table 2 Averaged Values of Test for Fluxural Strength Test for 3 Samples Under each Mold Type

Composite PlateVariations	Average FlexuralStrength, (σ, MPa)	Flexural Modulus (E = FL3/4bt3D, in GPa)
A	214.83	7.3600
B	205.87	8.6770
C	212.27	9.0296

Table 3 Averaged Values of Test for Flexural Strength Test for 3 Samples Under each Mold Type

Composite Plate Variations	Average Tensile Strength, (σ MPa)	Average Strain Value, (εaver. = Lu/Lo)	Young's Modulus (E = σT/ ε, GPa)
A	345.40	0.11	3.20

B	304.33	0.10	3.00
C	281.67	0.09	3.13

In this research work, the design of mono leaf spring process, the mechanical system under consideration is mainly subjected to bending stress rather than tensile or impact loading. Thus, critical attention was given to the sample type which can resist the maximum amount of bending stress (3 points bending loading condition) and the composite structure type 'C' fulfills this criterion. Hence, all the necessary design parameters (Density, Elastic modulus, Flexural Strength, Tensile Strength, etc…) have decided to be the values associated to the fabricated composite material type 'C'

Specimen Type	Impact Energy (Measured Value in J)	Impact Strength, J/m2 (Calculated Value)	Mean IS Value, in KJ/m2
CI1	7.2	144 KJ/m2	165 kJ/m2
CI2	7.4	148 KJ/m2	
CI3	10.1	202 KJ/m2	

V. E-GLASS/POLYMER (EGP) MONO LEAF SPRING DESIGN

In this section, the main idea of the analysis of stress, specific strain energy and maximum deflection so that to determine dimension/geometry required to apply the composite mono leaf spring for K2700 mini truck 2016 model truck relies on methods used in equation1, 2 and 3 in section-I where input material properties data taken from experimental result in section-II. Mold plate type C-preferred for this research over others due to less density

Assumptions adopted for the fiber matrix fabricated for the aforementioned application are described as follows. (a) Uniform traverse stress (b) perfect bonding between fiber and matrix (c) the composite considered isotropic, homogenous and linearly elastic without voids (d) the fabricate considered stress free. These assumptions are reasonable for macro-level analysis.

Data available for the analysis are half of the span-eye-to-eye length (L=860mm/2=430mm). Similar to section-I where effective length for SUP7 multi leaf spring determined, the hybrid composite leaf spring effective length for mono leaf calculated as: 2Le=860 mm – 2/3*54 mm = 824 mm Le=412 mm (half effective length of the EGP composite leaf spring). Static axle loading (determined in section-I) is 5252N. Thickness-to-width ratio 0.4 (Abebaw, 2017); b=2.5t. Elastic modulus in section-II determined to be 9GPa.

Using equation 4, $\delta_{max} = \frac{4FL^3}{Enbt^3}$ but substituting for b=2.5t; $\delta_{max} = \frac{4FL^3}{En(2.5t)t^3}$=$\delta_{max} = \frac{4FL^3}{2.5Ent^4}$. Solving for t yields $t^4 = \frac{4FL^3}{2.5En\delta_{max}}$ and therefore, $t = \frac{4FL^3}{2.5En\delta_{max}}$. With equivalent maximum deflection considered, solving for t yields: t=3.5 mm. The width of polymer mono leaf spring therefore becomes: b= 2.5t=8.8 mm

Checking for bending stress and maximum deflection using equation-3 and equation-4 yields much less stress induced and deflection for composite with values 120.485 MPa and 43.26 mm respectively compared to SUP7 multi leaf spring (676 MPa and 45.54 mm).

Finally, the weight of EGP mono leaf spring calculated using equation 5 so that to ensure whether the purpose of reducing specific weight without affecting load carrying capacity.

Where ρ is density of type-C fibe obtained in experiment in section-II (1.581 gm/cm3). V is volume of EGP mono leaf spring calculated from the geometry (Length=2L, width =b and thickness t): V=2L*b*t=2*86mm*8.8mm*3.5mm=5,297.6 mm3. Therefore much less weight achieved 82 N compared to weight of SUP7 multi leaf spring i.e. 147.299 N from section-II.

The final design geometry of the mono leaf spring made of EGP composite:

-t = 35 mm	-Span (2L) =860 mm	-Outer Eye Dia. = 40 mm
-b = 88 mm	-Camber(C) =77 mm	-Inner eye Dia. =20 mm

VI. A MODELING, ANALYSIS, SIMULATION AND RESULT SUMMARY

2D Model of the composite mono leaf spring, all important and necessary geometrical dimensions measured in millimeters which have been determined so far (in the above sections) are used appropriately. Hence, for proper 2D modeling of the composite mono leaf spring system, the following geometric parameters are used.

: Camber Height 'C' = 77 mm, Arch Height = C + outer eye radius, Width of leaf spring 'b' = 88 mm, Thickness of leaf spring 't' = 35 mm, Eye-to-eye length '2L', (full length) = 860 mm, and Main arch radius of curvature, R: C(2R+C) = L12. Where, C is the Camber and L1 is the half-length (span) of the mono leaf spring. Hence R = 1162 mm

2D Modell of the conventional leaf spring (SUP7), all important and necessary geometrical figures measured in millimeters which have been determined so far (in the above sections) are used appropriately. Hence, for proper 2D modeling of the conventional multi leaf spring system, the following geometric parameters are used. Camber Height 'C' = 77 mm, Width of leaf spring 'b' = 60 mm, Thickness of leaf spring 't' = 8 mm, Eye-to-eye length '2L', (full length) = 860 mm, and The 2D arch is drawn mainly by using 3-point spline geometry.

The sketch then to leaf spring width extruded to create steal leaf spring using extrude tool and assemble each leaf in the assemble window in SOLIDWORKS 2016. For SUP7, the sketch produced with corresponding lengths and assembled. Whereas for E-Glass mono leaf spring, the process is straight forward.

After solid (3D) model of SUP7 HCS leaf spring in SOLIDWORK 2016, Save that 3D model in IGES format. Import above 3D model in ABACUS Workbench static structural module for static analysis. Then the browsed solid model of the SUP7 HCS leaf spring done on SOLIDWORKS and saved as "IGES format" form looks like the following figure.

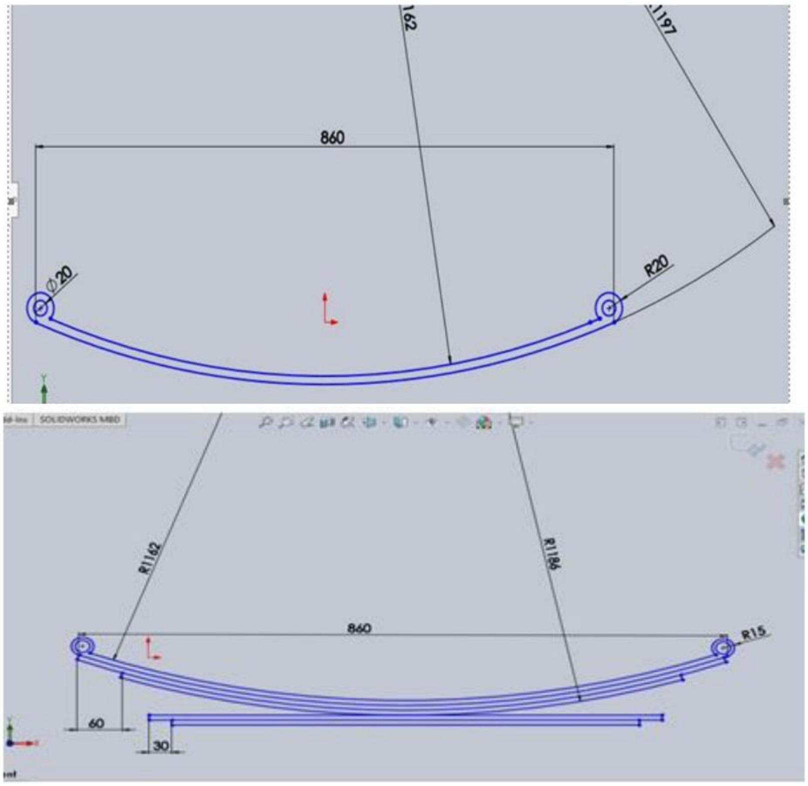

Figure 1 2D Model of E-Glass Fibe mono Leaf Spring and SUP7 Multi Leaf Spring

Software Implemented for this analysis is ABACUS. Meshing size is limited to computer compatibilities. Static analysis is considered for maximum static load of F=5252 N. Material used for SUP7 HCS leaf spring analysis is isotropic. Physical and mechanical Properties of SUP7 HCS leaf spring material in ABACUS work bench defined. Here all the required material constants and mechanical properties of the conventional leaf spring material has been inserted to the ABAQUS Work bench as shown in the snipped figure in Appendix. SUP7 HCS Density, young modulus and the poison ratio are the basic input variables for static analysis of suspension spring.

In SUP7 case, OPEN THE STEP DIALOGUE BOX used for BCs and applying the design load. Meshing imported in to appropriate and optimum numbers of seeds for better result by considering the Machin's capacity, the part geometry and time required for analysis. On the meshed part, boundary conditions applied and the design load located at the appropriate points. Finally the parts assembled for static analysis of the system.

Material used for composite leaf spring analysis is powder and emulsion chopped strand composite materials. Steps for Static analysis of EGP mono Leaf Spring using ABACUS. After solid model of EGP composite mono leaf spring in SOLIDWORKS 2016, Save that model in 'STEP P214' format. Import the above

3D model in ABACUS Workbench static structural module for static analysis. Then the imported solid model (3D model) of the SUP7 HCS leaf spring done on SOLIDWORKS and saved as "STEP format" form looks like the following figure

The results of both EGP composite mono leaf and conventional SUP7 HCS multi-leaf spring materials obtained from the static structural analysis is stated here. In this work, the suspension spring static structural analysis was performed using FEM by applying ABAQUS 6.13-1 workbench, that consist of a static structure. This helps to determine the maximum and minimum equivalent stress and displacement on the structural model.

The static structural analysis shows the characteristics of the stress and deformation of the structure caused by the applied static loading and boundary conditions. The following typical static structural analysis procedures on ABAQUS 6.13-1 workbench must be performed step by step till the appropriate job file has been created and submitted for further analysis. These steps are guidelines to use ABAQUS for FEM analysis. These are: Part>Property>Assembly>Step>Interaction>Load>Mesh>Optimization>Job> Visualization as shown in the figure below.

From the static analysis results, the von-mises stress in the conventional (SUP7 HCS) leaf spring is 189.20MPa and in EGP composite mono leaf spring is found to be 112.80 MPa. These indicates that composite material C has higher resistance to the applied static load.

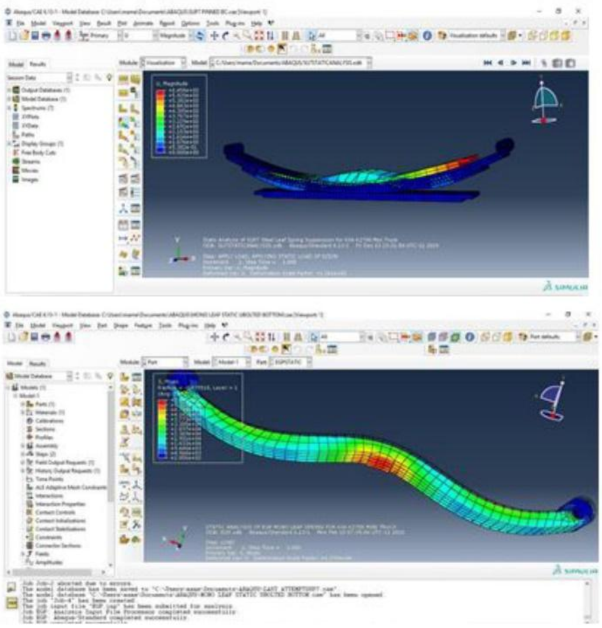

Figure 2 Equivalent (Von Mises) stress of SUP7 Mult leaf spring and EGP composite leaf spring

The design and static structural analysis of SUP7 HCS conventional leaf spring and EGP composite mono leaf spring has been carried out. Comparison has been made between EGP composite mono leaf spring with SUP7 HCS leaf spring having same design procedure and same loading condition. The stress and displacements have been calculated analytically as well as using ABAQUS 6.13-1 for SUP7 HCS multi leaf spring and EGP composite mono leaf spring. From the static analysis results, it is found that there is a maximum deformation of 10.81.mm in the case of conventional leaf spring and the corresponding displacements in EGP composite mono leaf spring is found to be 6.69 mm. The total deformation result of both EGP composite mono leaf and steel leaf spring of FEA are shown in figures 3.

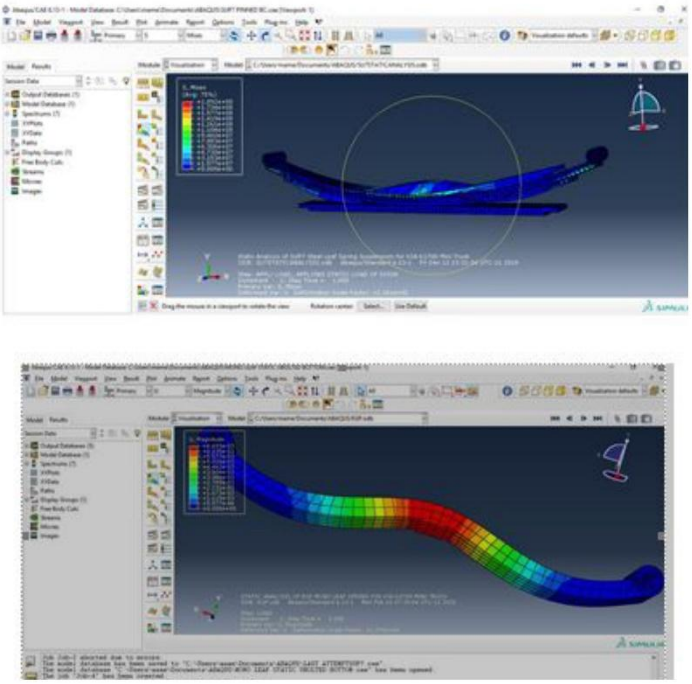

Figure 3 Total deformation of Conventional HCS multi- leaf spring and E-Glass Composite Leaf Spring

Important attainments of EGP composite mono leaf spring (Summary). The table below summarizes all important achievements because of considering the EGP composite mono leaf spring as a replacement for the conventional SUP7 HCS spring.

Table 4Comparison of the FEA of the EGP mono leaf spring and the SUP7 HCS multi leaf spring

Type of Leaf spring (based on material)	Max. Equivalent stress (Mpa) at 10,504 N	Max. Total deformation (mm) at 10,504 N	Mass (Kg)
EGP composite mono leaf spring	112.80	6.690	4.19
Conventional (SUP7 HCS) leaf spring	189.20	6.648	15.02
Percentage difference (%)	40.32%	0.63%	72.01%

The E-Glass fiber reinforced Polyester composite was manufactured and its mechanical properties such as the tensile strength, compression strength and flexural strength properties are determined using experimental investigation. These fundamental material properties are the guaranty of the reliability of the composite material and of its usage for leaf spring application. From experimental test result, material C has highest flexural strength and lowest density and material A has highest tensile strength.

As part of this research work, a comparative study has been made between the conventional HCS spring and EGP composite mono leaf spring with respect to weight. According to the comparison output, EGP composite mono leaf spring leaf spring achieved a reduction in mass of the suspension element. Hence, it reduces the total weight of the conventional multi leaf spring from 15.02 Kg to 4.19 Kg. Or it can be expressed in terms of percentage weight reduction. According to static analysis and simulation , it has been shown that suspension system with comparative strength and stiffness has been attained with E-Glass composite mono spring weighing one eighth of conventional SUP7 hardened steel multi leaf spring. Lighter weight of EGP mono leaf spring is attributed to lower elastic modulus and better geometric (free of notch) characteristics of the composite materials.

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