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Research/Technical Note

Development of a Carbon Fibre Reinforced Polymer for Exhaust Pipe of Two Stroke Engine

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Abstract: Engine noise production performance is strongly dependent on gas dynamic phenomena and hardness of the material of the exhaust systems. Careful design of the manifolds enables the engineer to manipulate these characteristics but none has treated a way to damp these vibration and its frequencies. Solidworks 2014 and Ansys workbench 4.0 are used to investigate thermal and modal analysis on a heat resistant 40% carbon glass fibre reinforced polyester resin. The steady state analysis in fig. (3), shows a temperature distribution of 193.1°C, total heat flux of 30737(W/m^2) and a direction heat flux 18565(W/m^2). Considering the transient heat analysis a temperature distribution 139.59°C, total heat flux of 170370(W/m^2) and a direction heat flux 108810(W/m^2). The modal analysis reveals a displacement of 1.4939m at 6.7011Hz in x-axis direction depicting the direction of the exhaust gas emission.

Keywords: Thermal and Modal Analysis, Vibration Absorption, Carbon Fibre Reinforced Polymer Exhaust Pipe

1. Introduction

Vehicles are one of the dominant sources of urban pollution in developing world that threatens both people's health and economic activities [2]; [3]. While this is common to growing urban areas throughout the world, it is particularly severe in Nigeria where majority of vehicles are two-stroke motorcycles [1]. The demand for owning a motorcycle is on a soaring path [1]. It is clearly observed that the population of all types of motorcycles is growing fast to the extent that besides goods and parcels, passengers are also moved by such mode of transportation in Nigerian cities and towns [1]. The effect of the geometry of the exhaust pipe of a motor cycle researched in the work as it affects the performance of the engine and pressure characteristic of the gasses. [4]

The strength and stiffness of a composite build up depends on the orientation sequence of the plies. The practical range of strength and stiffness of carbon fiber extends from values as low as those provided by fiber glass to as high as those provided by titanium. A fiber is the primary load carrying element of the composite material. The composite material is only strong and stiff in the direction of the fibers. When a polymer breaks down in thermal decomposition, the following types of products may be formed [7]: (1) combustible gases, e.g., methane, ethane, and carbon monoxide; (2) noncombustible gases, e.g., carbondioxide, hydrogen chloride, and hydrogen bromide; (3) liquids, which are often partially degraded polymers; (4) finely divided solid particles consisting of decomposing polymer fragments or soot in the combustion gases; and (5) discrete solids in the form of a carbonaceous residue or char. The most efficient way to prevent polymer combustion is to design inherently fire-resistant polymers that have high thermal stability, resistance to the spread of flame, and low burning rate even under high heat flux [13]. Most polymers with high thermal stability are intrinsically fire resistant. Due to their high decomposition temperature, the initial breakdown will be effectively prevented and the combustion process will not be initiated. This high-temperature property of polymers can be improved by increasing the interactions between polymer chains or by chain stiffening [14]. In all, polymers that have high thermal stability and generate less flammable volatiles on decomposition are the most desired fire-resistant polymers. There are three general types of structures for the intrinsically fire-resistant polymers: linear single-strand polymers consisting of a sequence of cyclic aromatic or heterocyclic structures, ladder polymers, and inorganic or semi organic polymers [14]. So far, most carbon-based, fire resistant polymers are prepared by incorporating highly stable, rigid, aromatic, or heterocyclic ring systems directly into the polymer chain [14], such as polyimide (PI), polybenzoxazole (PBO), polybenzimidazole (PBI), and polybenzthiazoles (PBZT). High Heat Resistant TPU as thermoplastic polyurethanes (TPU) could be used in this regaurd. [15]

2. Acoustic

Among the physical phenomena which can give origin to noise are as follows

I. mechanical shock between solids,
II. unbalanced rotating equipment
III. friction between metal parts,
IV. vibration of large plates,
V. irregular fluid flow, etc

In (V), we can discussed the source of hot air velocity profiles from the two stroke engine that goes through the exhaust pipe system. Velocity of the air stream generation within the megaphone and the converging cone of the exhaust pipe results pressure variation characteristics in the pipe. The sound produced is due to these pressure levels. Definition of sound pressure level and decibel (dB)

$$L_P = 10log\left(\frac{p}{p_{ref}}\right)^Z \quad (1)$$

$$L_P = 20log\left(\frac{p}{p_{ref}}\right) \quad (2)$$

Where p is the pressure of the sound wave and p_{ref} is the reference pressure and equals 2 x 10 -5 Pa (20 μPa). The reference pressure corresponds to a just perceptible sound level at a frequency of 1000 Hz. The letter L used to represent the sound pressure level corresponds to "Level". The subscript P indicates the pressure level. This subscript is often omitted. In practice, the decibel (dB), is used rather than centimeters rather than metres for short lengths. The sound scale goes from 0 dB to approximately 140 dB. A sound on the hearing threshold would have 0 dB level. The pain and hearing loss threshold is at 140 dB. [17]

This work is motivated by the worrisome noise found in most parks of motor cycles that can cause damage to the ear in a long term exposure. Besides, the availability of polymers and fibres or low cost technology in the production of polymers than metals extraction and processing from there ore, and tasking technology of the components production. The rate of noise proliferation from motorcyclists in urban centers is hazardous to the hearing ability of people living around parks, and passengers in the parks. The hearing range for a normal human being is 20Hz to 20,000Hz and a sound pressure of 60 to 80decibel is tolerable. The alarming noise produced in most of these parks can cause grievous damage to the ear. This could be solved through developing a material that could damp these vibrations and its resonating effect. Hence use of glass fibre reinforced polyester resin for the development and manufacture of a two stroke motor cycle engine will reduce noise in motorcyclists parks and urban centres since the sound characteristic will be tuned and amplitude of vibration reduced critically.

This work aimed at developing a polymer matrix composite that have high absorption ability for vibration through good damping coefficient and can survive High temperature resistance for harsh and demanding application, Excellent chemical resistance and hydrolysis resistance, Excellent biogas resistance, Low temperature (-40°C) bending properties Superior abrasion and cut through resistance lasting longer and reducing overall cost. Revealing a stability in absorption of vibration than a chrome plated steel pipe to offer industry leading toughness and durability, hydrolysis resistance, chemical resistance and low-temperature flexibility.

Permanent hearing loss due to sound levels in the workplace has been a historical cause for concern. Every year over 300,000 healthy life years are lost due to occupational hearing loss in developed countries, nearly 4 million in developing countries [18]. Mechanical Loss Coefficient as a materials ability to dissipate vibration and Young Modulus that is the stiffness of an engineering material. Using Granta software 2010, varieties of different steel were selected and studied. The effect of porosity on sound is of interest, so porous materials were considered. A thorough microstructural analysis of the materials reveals a correlation between microstructure and the sound output. A relationship between the ratio of a material's Young Modulus / Hardness to the sound output was seen; however, more data are needed in this case to further validate the relationship. Hence, this paper work suggests a reinforced polymer for exhaust pipe development for a motor cycle. Several types of porous materials were looked into, such as polyurethane based foams, fiber glass, activated carbon fiber, and spray cellulose.

3. Design Analysis

Methodology

The model for the glass fibre reinforced polymer is designed using SolidWorks and built with the composite material and simulated with a computer knowledge base software –Ansys Workbench. The model analysis carried out are structural, thermal, and modal analysis. Results be discussed and analyzed for validation.

Model

The 3-D model for then composite reinforced polymer exhaust system is designed with solid works 2013 and built in Ansys workbench environment.

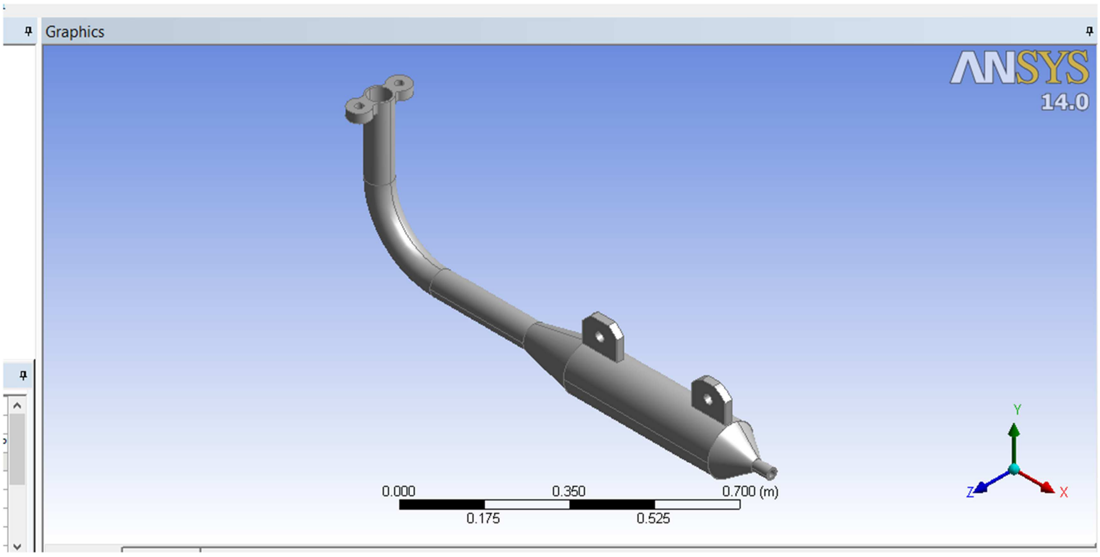


Figure 1. *3-D model of the glass fibre reinforced polyester resin exhaust pipe.*

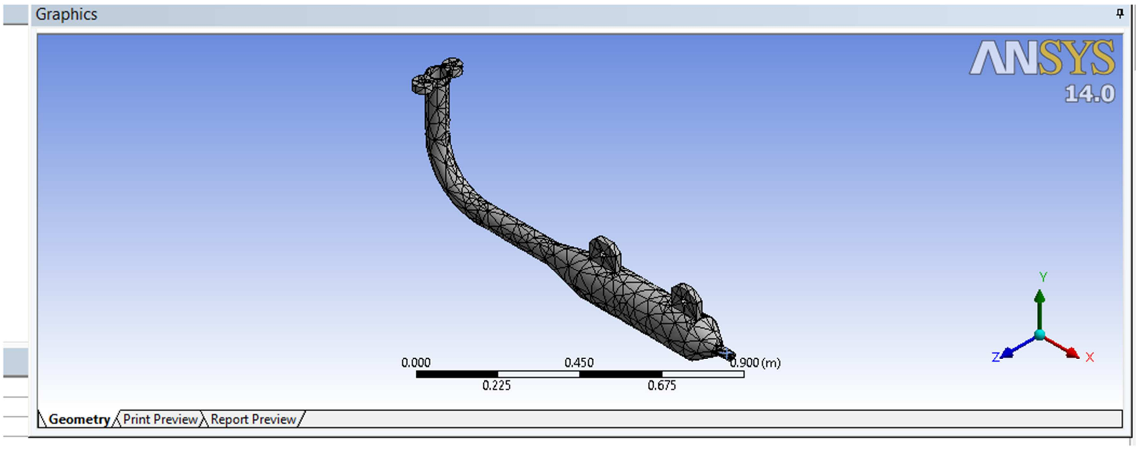


Figure 2. *3-D Meshed Model Of The Glass Fibre Reinforced Polyester Resin Exhaust Pipe.*

4. Material

The composite is made of 40% carbon glass fibre reinforced polyester resin.

Table 1. *Mechanical Properties of Glass Fibre.*

s/n	properties	value
1	Density (Kg/m^3)	1900
2	Young modulus (Pa)	1.25×10^{10}
3	Bulk modulus (Pa)	1.25×10^{10}
4	Poisson's ratio	0.33
5	Compressive strength (Pa)	2.7×10^8
6	Hardness Vickers (Pa)	3.65×10^8

Source: Granta CES edu pack (2011)

Table 2. *Thermal Properties of Glass Fibre.*

S/n	Properties	Values
	Thermal conductivity(W/mC)	1.11
	Specific heat capacity (J/KgC)	1.21×10^3
	Maximum service temperature c	138
	Heat deflection temperature @ 1.8mpa @ 1.8mpa	160

Source: Granta CES edu pack (2011)

Table 3. *Mechanical Properties of Polyester Resin (Polyester Cast Flexible).*

s/n	Properties	Value
1	Density (Kg/m^3)	1200
2	Young modulus (Pa)	3.08×10^8
3	Bulk modulus (Pa)	9.04×10^8
4	Poisson's ratio	0.452
5	Compressive strength (Pa)	1.99×10^7
6	Hardness Vickers (Pa)	8.28×10^6

Source: Granta CES edu pack (2011)

Table 4. *Thermal Properties of Polyester Resin (Polyester Cast Flexible).*

S/n	Properties	Values
	Thermal conductivity(W/mC)	1.61
	Specific heat capacity (J/KgC)	1.7×10^3
	Maximum service temperature c	128
	Heat diffliection temperature @ 1.8MPa	160

Source: Granta CES edu pack (2011)

Table 5. *Values for Model Building and Simulation.*

s/n	Properties	Value
1	Density (Kg/m^3)	1200
2	Young modulus (Pa)	3.08×10^8
3	Bulk modulus (Pa)	9.04×10^8
4	Poisson's ratio	0.452
5	Compressive strength (Pa)	1.99×10^7
6	Hardness Vickers (Pa)	8.28×10^6
7	Thermal conductivity(W/mC)	1.61
8	Specific heat capacity (J/KgC)	1.7×10^3
9	Maximum service temperature c	138
10	Temperature 1 ambient C	30
11	Temperature 2 on the surface C	250
12	Temperature3 on interior surface C	380

Steady State Thermal Analysis

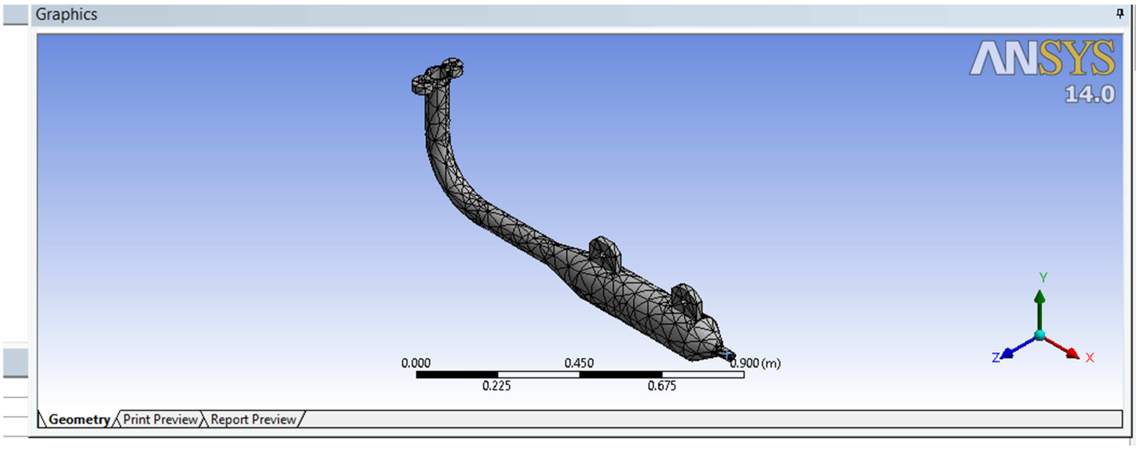
Table 6. *Results of the Steady State.*

Coordinate system			Global Coordinate System	
	temperature	Heat Flux		
Minimum	-40.535 C	2.5585 (W/m^2)	-45723(W/m^2)	1.6499×10^{-4}
maximum	380 C	50709 (W/m^2)	50709 (W/m^2)	11762

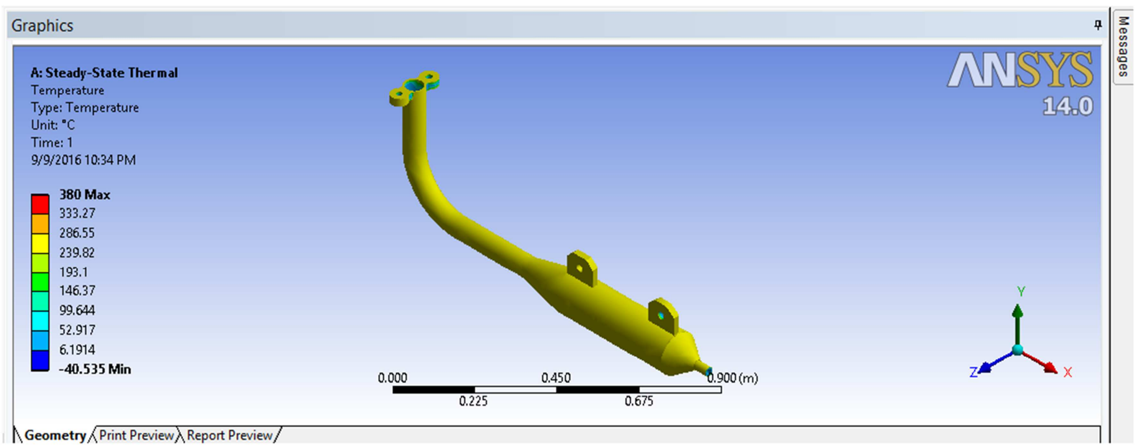
Culled from report preview

Mesh details

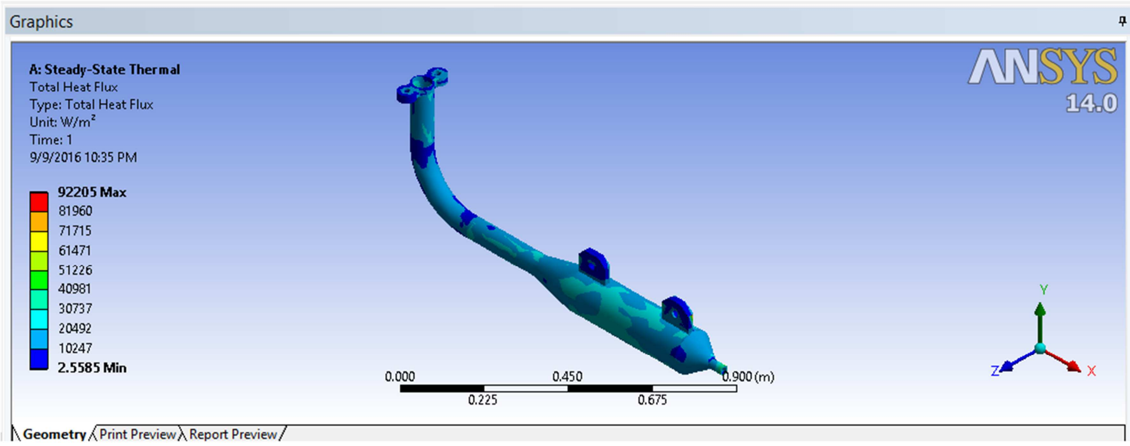
Statistics	
Nodes	6682
Elements	3449



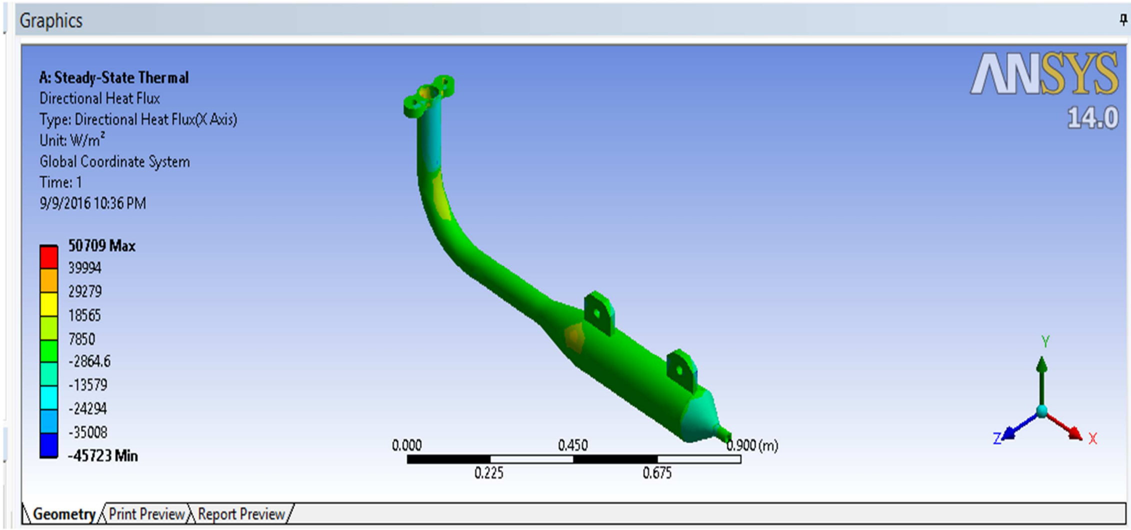
(i). 3-D Mesh modell



(ii). Temperature Distribution



(iii). Total Heat Flux Distribution



(iv). Directional Heat Flux Distribution

Figure 3. *Solution of stead state thermal analysis.*

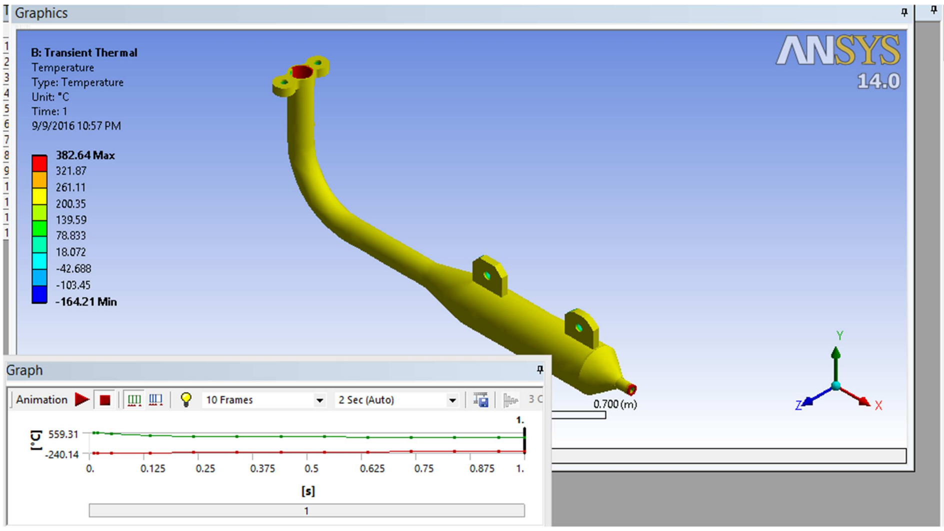
Transient Thermal Analysis

The transient heat analysis allows understanding of the heat distribution in the polymer composite exhaust pipe over a definite time of the usage. The solution variables temperature distribution and heat flux distribution are in figure

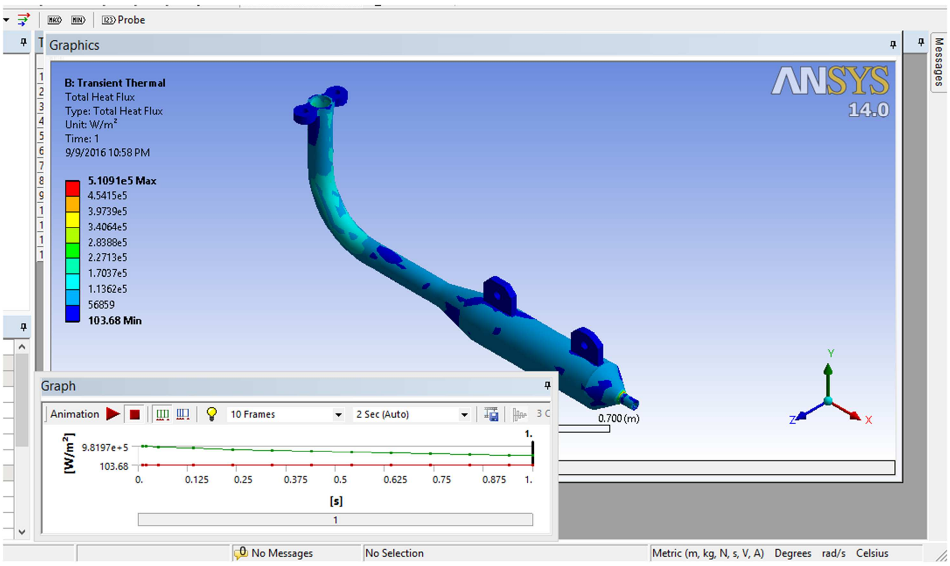
Table 7. *Results Of The Transient Thermal Analysis Of The Composite Polymer.*

Results				
Minimum	-164.21°C	103.68 W/m²	-2.824e+005 W/m²	8.6402e-004
Maximum	382.64°C	5.1091e+005 W/m²	3.0441e+005 W/m²	5.88E+05
Minimum Value Over Time				
Minimum	-240.14°C	103.68 W/m²	-5.8547e+005 W/m²	8.6402e-004
Maximum	-164.21°C	197.53 W/m²	-2.824e+005 W/m²	1.2238e-002
Maximum Value Over Time				
Minimum	382.64°C	5.1091e+005 W/m²	3.0441e+005 W/m²	5.88E+05
Maximum	559.31°C	9.8197e+005 W/m²	8.819e+005 W/m²	9.78E+06

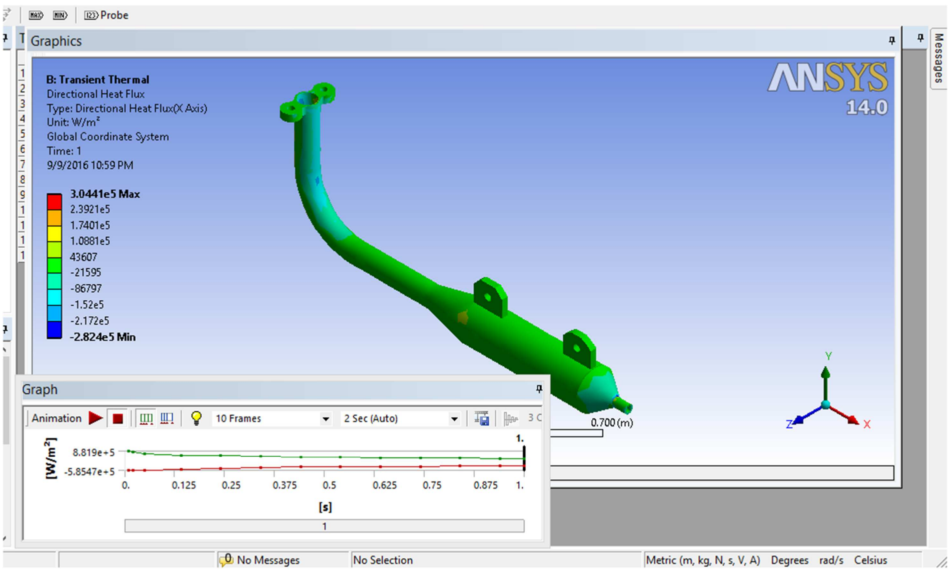
Sourced: Culled from Report preview of the simulation



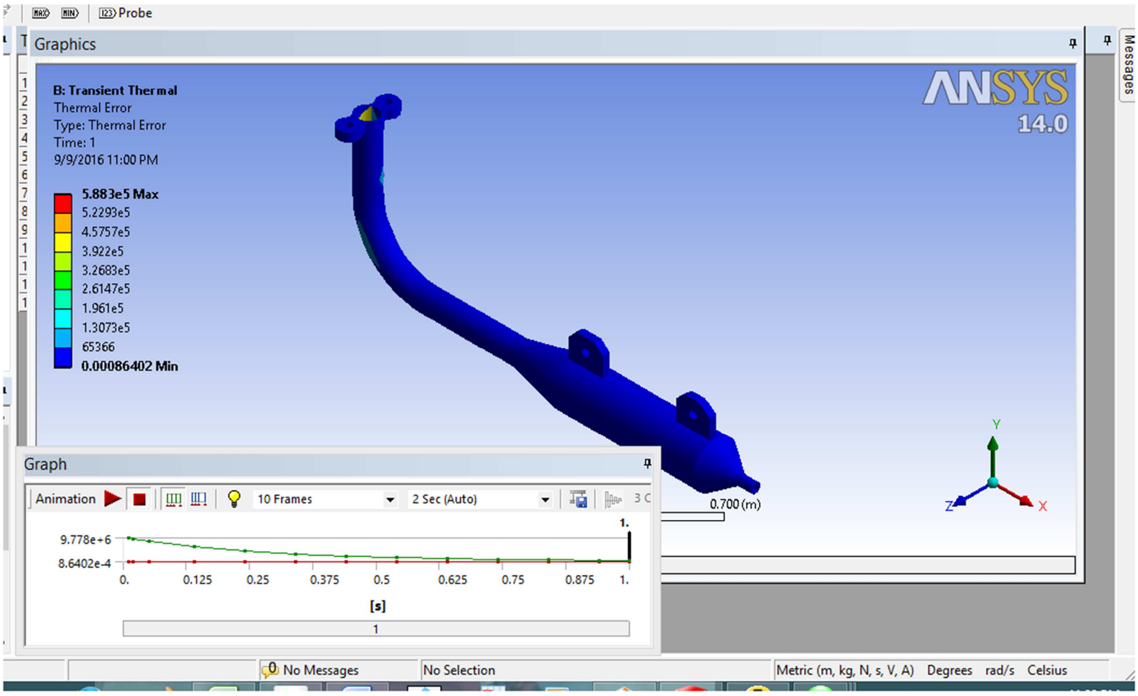
i. Temperature Destribution



ii. Total Heat Destribution



iii. Directional Heat Flux



iv. Error

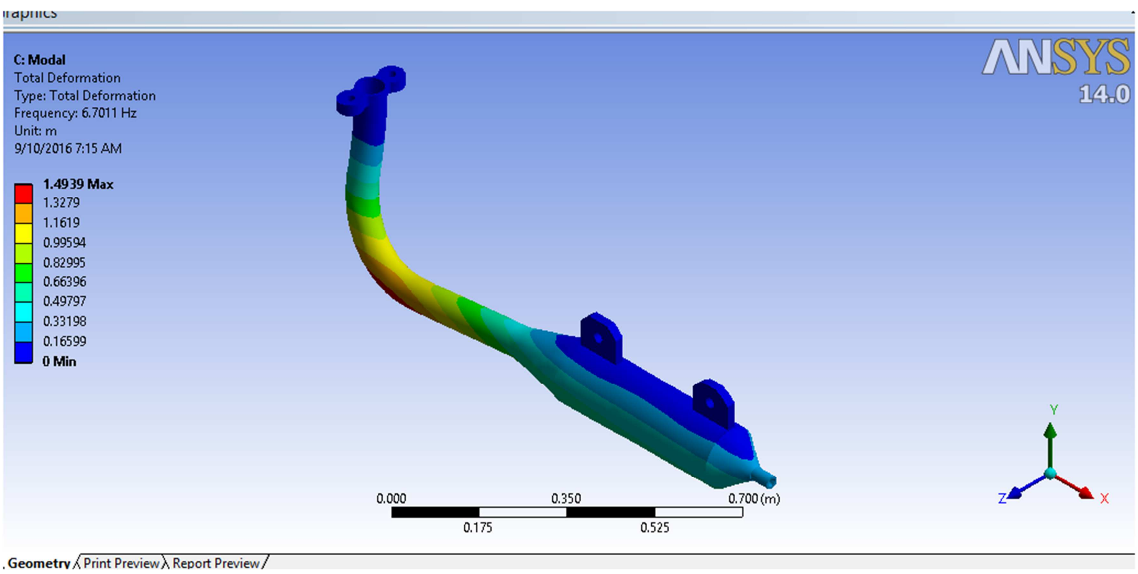
Figure 4. *Solutions Of The Transient Thermal Analysis Of The Polymer Matrix Exhaust Pipe.*

Modal Analysis

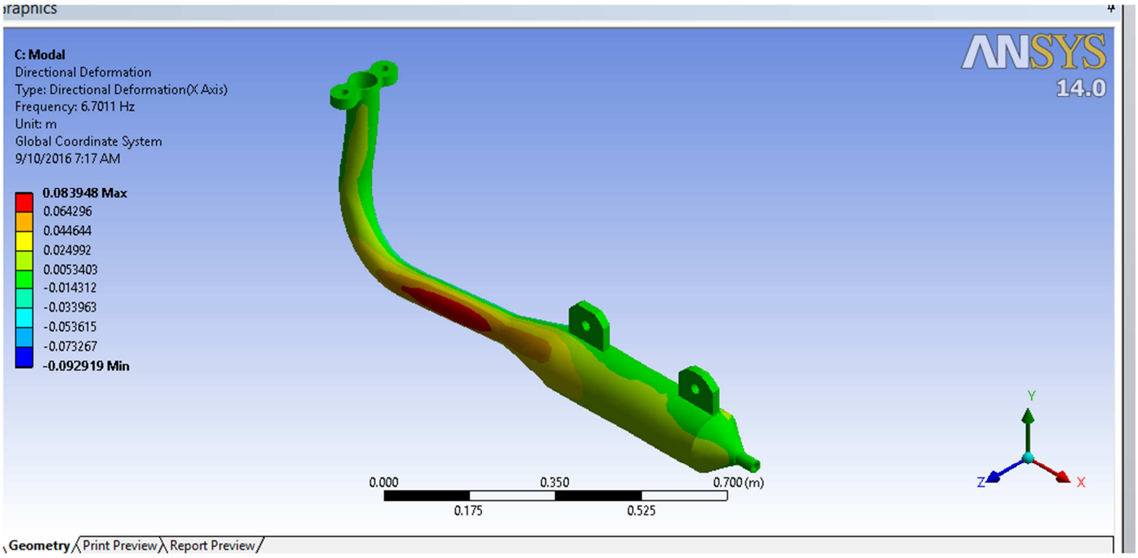
The modal analysis give the vibration along the X-axis as the orientation of the exhaust gas emission direction

Table 8. *Modal values and frequencies.*

Mode	Frequency [Hz]
1.	6.7011
2.	9.9532
3.	16.864
4.	18.943
5.	27.927
6.	30.253



a. Total Deformation Along X-Axis

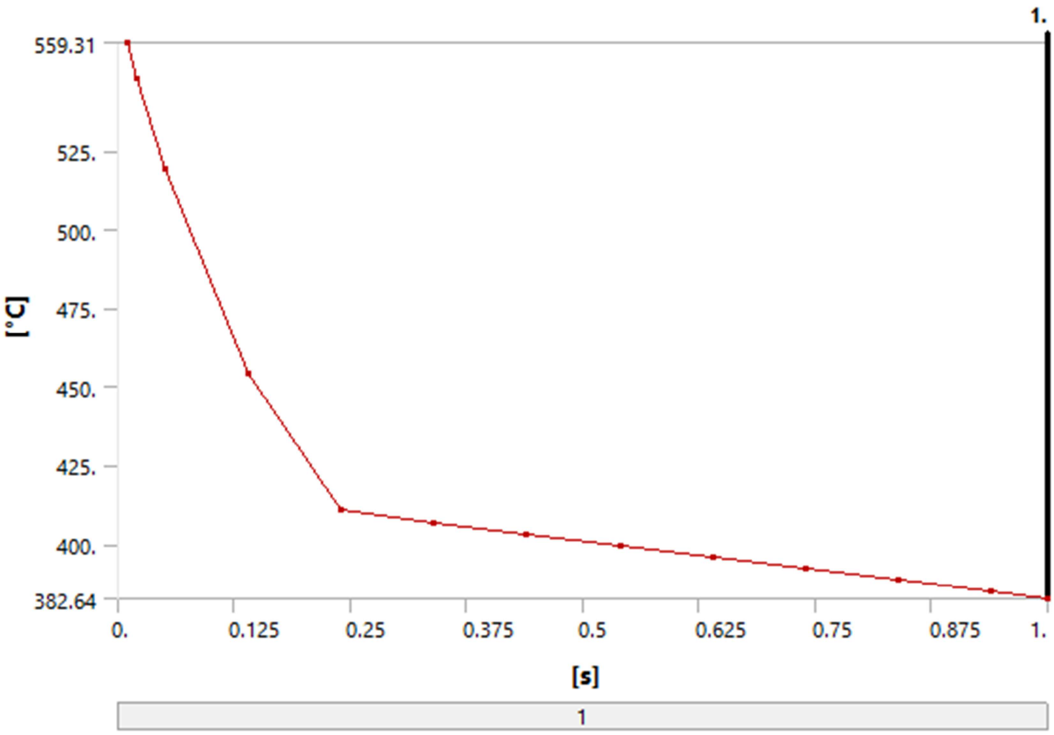


b. Direction Deformation Along X-Axis

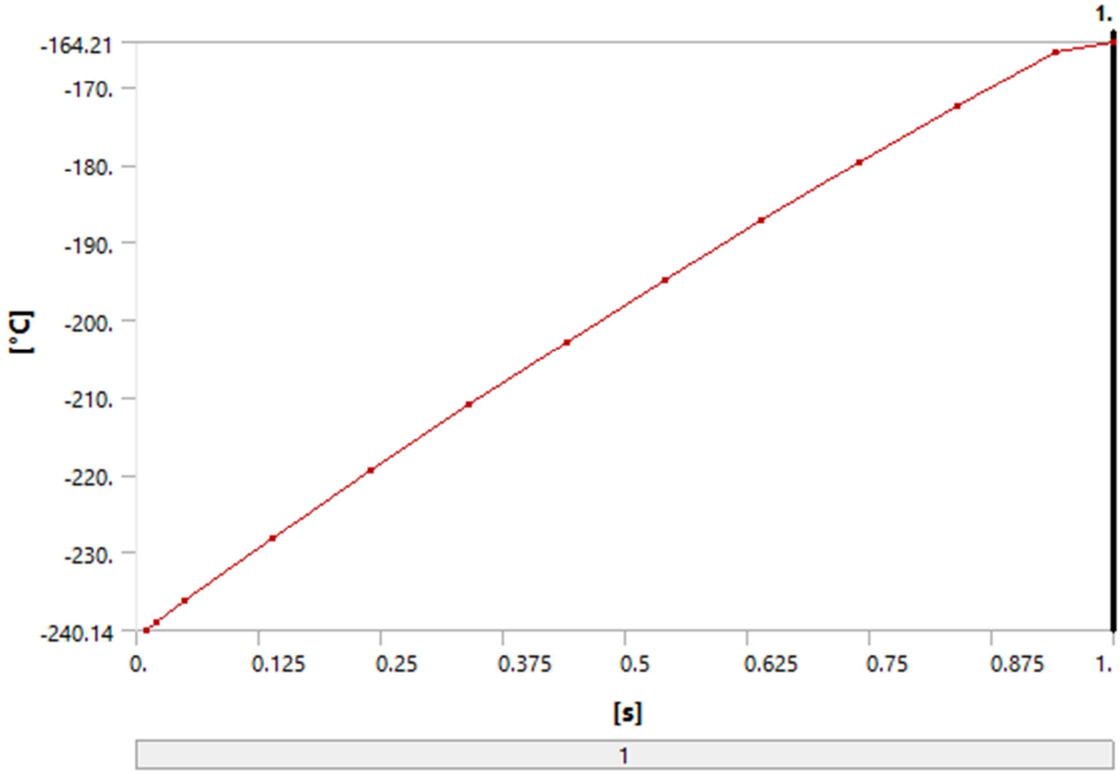
Figure 5. *Deformation Of The Exhaust Pipe Polymer Composite.*

Graphs

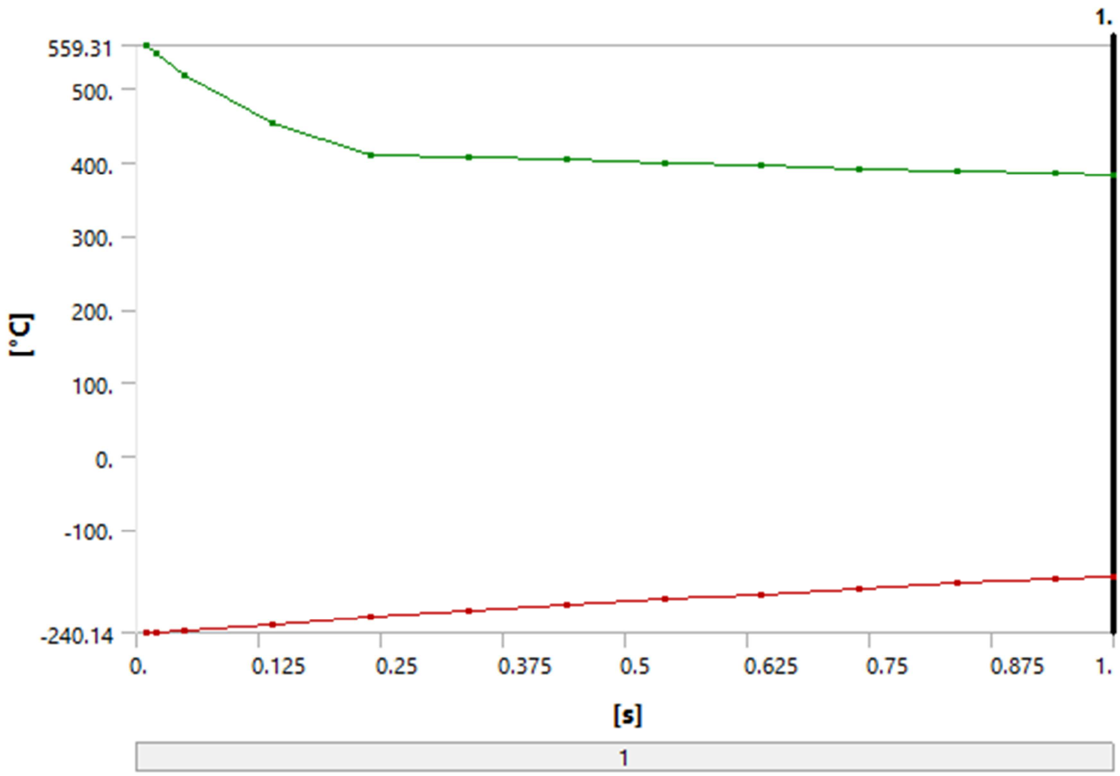
The graphs for the thermal analysis as given



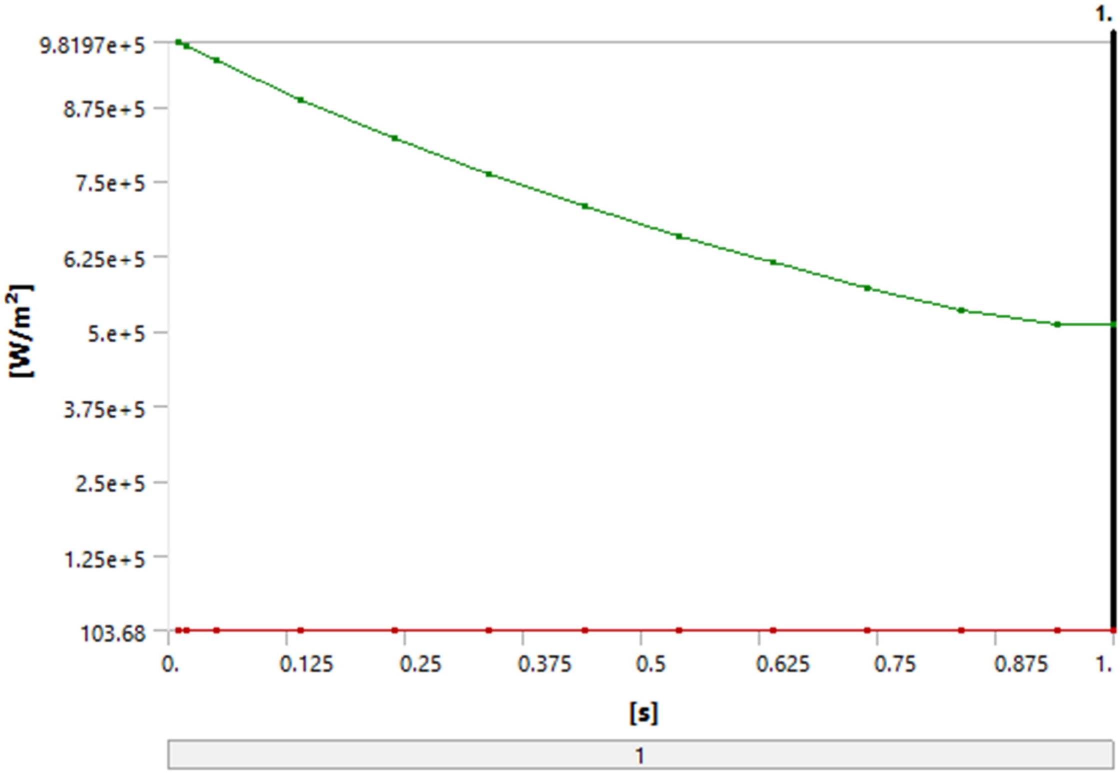
a. Temperature - Global Maximum



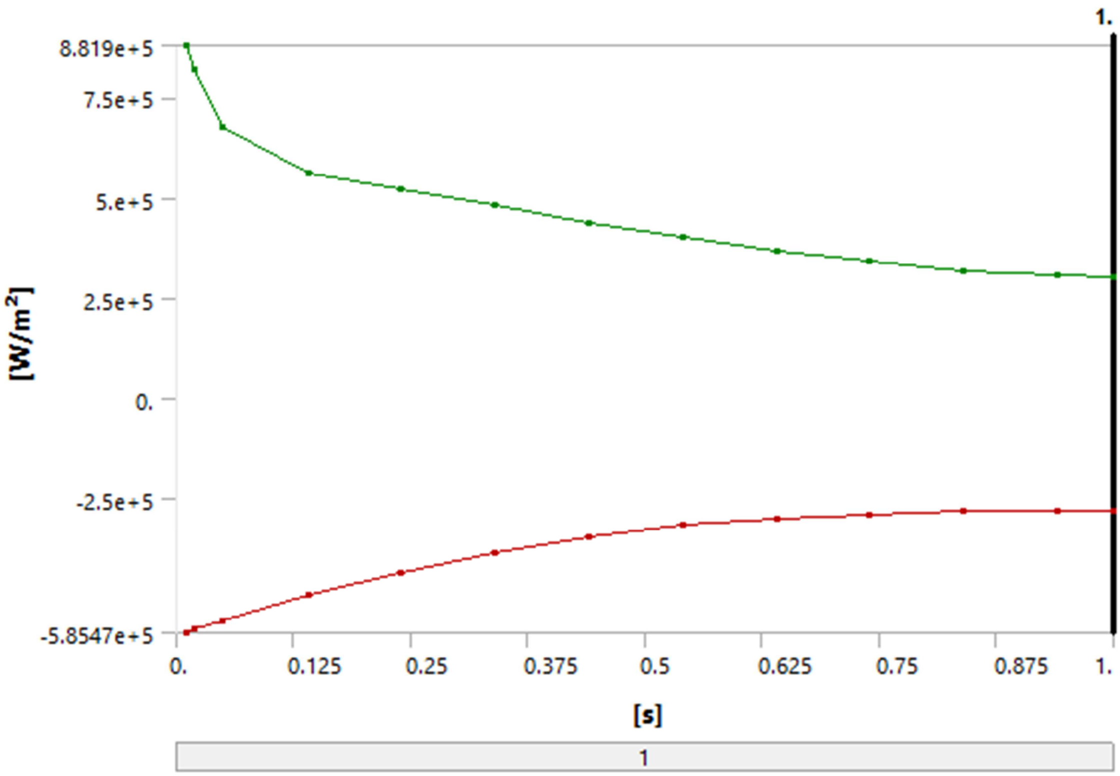
b. Temperature - Global Minimum



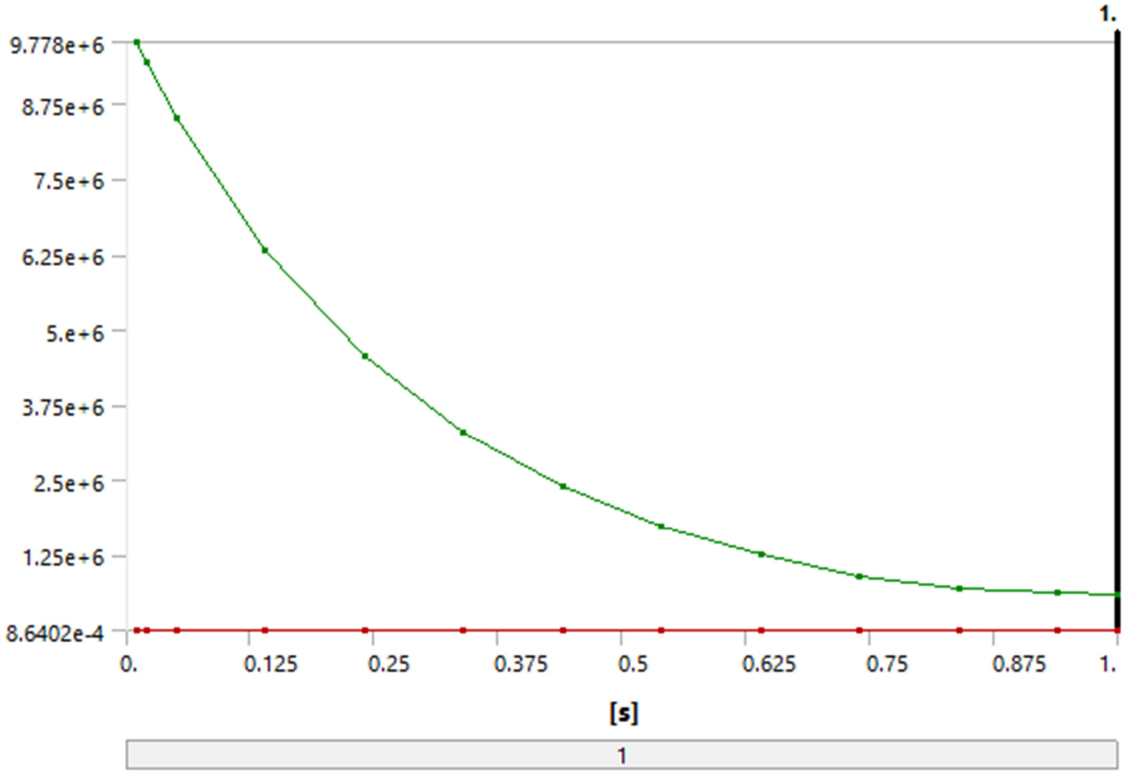
c. Temperature distribution for minimum and maximum temperature in in the composite exhaustpipe



d. Total Heat Flux distribution for minimum and maximum temperature in in the composite exhaustpipe

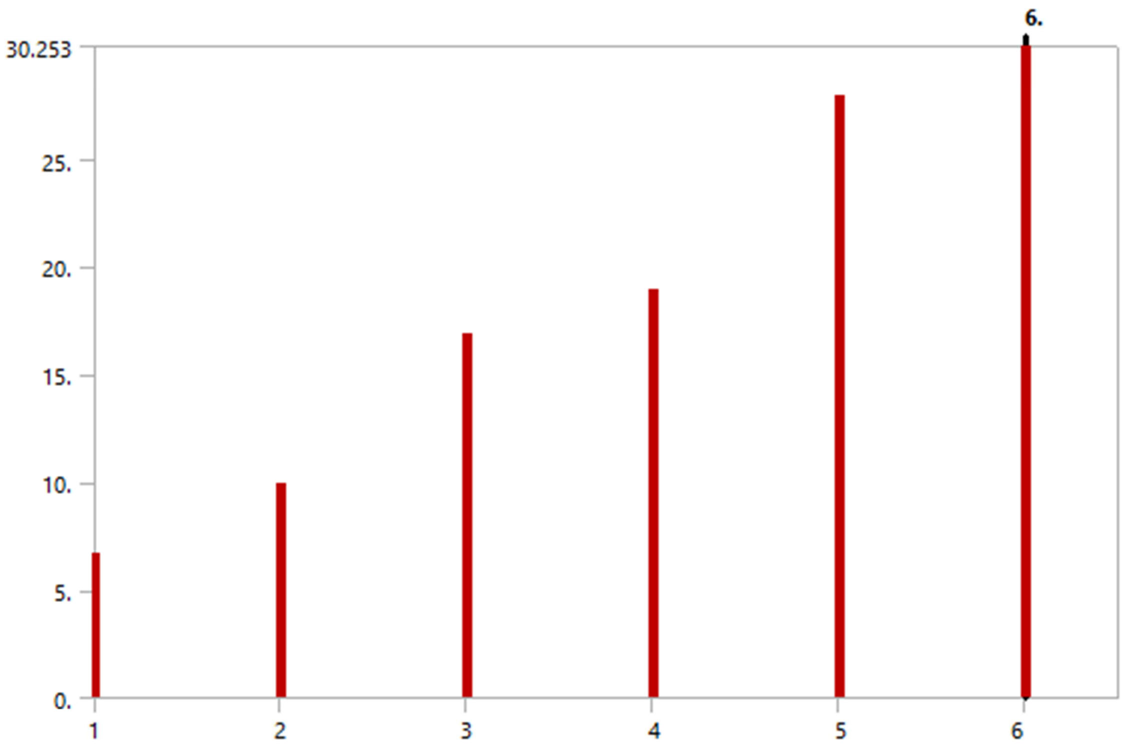


e. Directional Heat Flux for minimum and maximum temperature in in the composite exhaustpipe

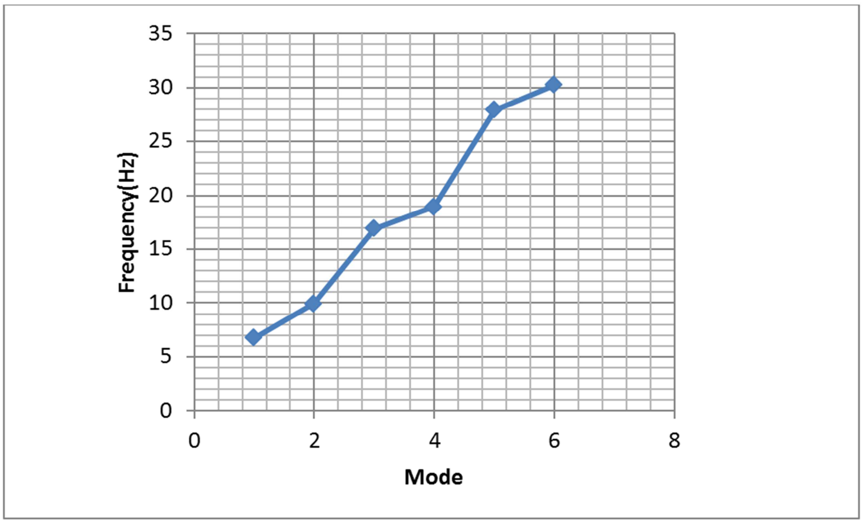


f. Thermal Error for minimum and maximum temperature in in the composite exhaust pipe

Figure 6. *Graphical Analysis Of The Transient Thermal Analysis.*



i. Modal Analysis Frequency



ii. Frequency Increases With Increase In The Modes(Amplitude) Of Vibration

Figure 7. *Modal Analysis Of The Composite Polymer Exhaust System.*

5. Discussion

The development of a fibre reinforce polymer for an exhaust pipe of a motor cycle is provoked by the unhealthy noise generated by motor cycles in major urban parks and the long term effect on the hearing ability of the users and people living around such park. From the steady state analysis in fig. (3). show a temperature distribution of 193.1°C, total heat flux of 30737(W/m^2) and a direction heat flux 18565(W/m^2). Considering the transient heat analysis a temperature distribution 139.59°C, total heat flux of 170370(W/m^2) and a direction heat flux 108810(W/m^2). The modal analysis reveals a displacement of 1.4939m at 6.7011Hz in X-axis direction depicting the direction of the exhaust gas emission. From the analysis, the composite polymer for an exhaust pipe system can withstand the thermal condition as the black body that can radiate this heat to the environment.

6. Conclusion

This work had shown case the potentials of polymer composites in thermal environment and their availability to take over the metals that are costly in extraction, processing and manufacturing. The gas flow velocity values and the pressure management dependent on the geometric configuration of the exhaust pipe system but the material in use governs the sound intensity hence the porosity of the composite used will absorb the sound and vibration. A well determined geometrical configuration is needed to yield acceptable engine and sound performance characteristics. But the use of this polymer composites will go a long way to reducing noise production and fine tune the sound characteristics of the exhaust system.

Future Work

A work bench practical model should be developed of a glass fibre reinforced polymer for exhaust pipe system and a comparative work should be done between the composite polymer model and the chromium plated stainless steel model of the exhaust system.

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