DESIGN AND ,THERMAL AND STRESS ANALYSIS OF WORKING SPUR GEARS IN POWER TRANSMISSION

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ABSTRACT

Gears are the mechanical components which are used to transmit power from source through shaft. Hence serve as a most significant component. During power transmission there is contact between teeths of meshing gears due to this contact there are wear and bending stresses on the gear tooth. Also considering friction ,so there is also heat generated on the surface of the gears. Under high speed condition there can be flashing between teeths which can wear out the surfaces and if the gears are lubricated the temperature difference can create distortion of tooth profile. Conclusively there are losses due to contact stresses and heat. The more type of losses can be made into account but in this project our main focus is on losses due to these two only. So failure can be caused due to bending stresses, wear stresses and heat generation. So mathematical design of the gear and choice of material is made accounting beam strength, wear strength and heat flux. In this project design is made in AUTOCAD on the basis of given data and conditions after making theoretical analysis through Lewis and Hertz equation. After that the obtained mathematical design through theoretical analysis is tested and compared in ANSYS simulation software using material of data given (C-45 Steel) and New Proposed Material SETS [SET-1(C55Mn75 & C55Mn75),SET-2 (Carbon Fibre & S- Glass), SET-3 (Brass & Low Alloy Steel)] . Comparisons and between different SETS and final conclusions are made on the basis of Deformations, Equivalent Stresses , maximum principal stresses, maximum heat flux rate and maximum temperature induced. And also theoretical analysis and FEM is compared for material in given data. After that the best material SET is concluded for the mathematical design.

Keywords: Analysis, Beam Strength , Wear Strength, Heat Flux , Lewis, Hertz.

I. INTRODUCTION

With the invention of the engine (thermodynamic) and motor (electric) the key to run on road was probably discovered but the problem was not yet over because through engine or motor and wheel one can advance only in forward direction so there was a need to invent some component which can channelize power from source in different direction this and many such problems which involve transmission of power and velocity led to the invention of gear and many complex machine components like differential. It is obvious that during power transmission the gear tooth will be in contact, thus creating contact stresses and significant amount of heat. And this is a well known fact that this gear as a component will not be used one time or two time , it will be used innumerable times so there will be fatigue caused in the material and if this reaches above the elastic limit of the material then it will fail (Fracture). So therefore to design gear on the basis of these limits should be the primary concern. Therefore to analyze these conditions and limits before designing the gear for given loads and material is extremely important. In earlier researches it is found that there are mainly two types of contact fatigue stresses i.e. bending and wear stresses. Bending stresses occur due to the tangential load on the tooth which may cause failure at the fillet section due to high stress concentration factor. Wear stresses occur due to surface wear and depend on hardness of the surface ,at the moment when stresses rise above the elastic limit the affect of wear sresses comes into play if the surface hardness is not enough to bear the plastic stresses then the surface will start tearing and ultimately fracture occurs. Mining machine uses traction gearboxes in transmission system. It consists of single pinion and gear setup and these gears are also known as speed reducer, gear head, gear reducer etc. which consists of bearings and set of gear shafts. Gear analysis was performed using analyticalmethods approach but nowadays computers have become more developed and use for numerical models to predict fatigue behaviour. In manufacturing ,power transmission is the most important. This is due to the efficiency of every machine depends on the amount of power loss during the process. Hence ,the inventions of gears are the best methods of transmitting power between the shafts. Usually , gears are used to transmit torque and angular velocity. The increasing demand for quiet power transmission in machines ,vehicles, elevators and generators has create a growing demand for a more precise analysis of the characteristics of gear system. In the automobile industry, the largest manufacturer of gears, higher reliability and lighter weight gears are needed as lighter automobiles continue to be in demand.

Apart from the physical effects like bending , wear and deformations ,thermal effects also impact the performance and life of the gear. As meshing teeths of the gear generate significant amount of heat due to friction which create high temperature which may melt the gear tooth and consequently weld them at the point of contact this phenomenon is known as scoring effect. Heat produced creates a temperature difference between meshing gears and if this temperature difference rises more than 30 degree centigrade and also if gear is lubricated than even at low immersion ratio of gear in lubricant the power loss may be minimum but there may be distortion of tooth profile which may make it inefficient and also not capable of performing the function for what it was designed. Therefore from above discussion it is clear that the thermal effects should also be considered while designing of gear.

Spur gears are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radically, the edge of each tooth is straight without angle and aligned parallel to the axis of rotation. In spur gears the design parameters play a major role in determination of stresses. The American Gear Manufacturing Association set the AGMA standard for spur gear design. The simplest motion of two external spur gears can be seen by an example of two external rotating cylinders, if sufficient friction is present at the rolling interface. The main disadvantage of these rotating is the possibility of slip at interface which is avoided by adding meshing teeth to rolling cylinders. This is cylindrical shaped gear in which teeth are parallel to the axis. It has the largest applications and, also, it is the easiest to manufacture. They are simple in construction, easy to manufacture. They have highest efficiency and excellent precision rating. They are used in high speed and high load application in all types of trains and a wide range of velocity ratios. Hence, they find wide applications right from clocks, household gadgets, motor cycles, automobiles, and railways to aircrafts. Spur gears are regularly used for speed reduction or increase, torque multiplication, resolution and accuracy enhancement for positioning systems. The teeth run parallel to the gear axis and can only transfer motion between parallel-axis gear sets. Spur gears mate only one tooth at a time, resulting in high stress on the mating teeth and noisy operation Designing highly loaded spur gears for power transmission that system are both strong and quiet requires analysis methods that can easily implemented and also provide information on contact and bending stresses.

II. METHODOLOGY

This project is implemented following these steps

Theoretical Analysis using LEWIS Equation

Given data is : power to be transmitted by Motor =1000 Kw , pinion material= Cast Steel 0.2% C , gear material= C-45 Steel , n1=1000 rpm(pinion angular velocity), n2=310 rpm(gear angular velocity), 20 degree full depth involute, AllowableStress2 (Cast Steel 0.2% C)= 138 MPa , AllowableStress1 (C-45 Steel)= 207 MPa , Ft1=18486.31 N(Tangential tooth load on Pinion), Ft2= 3696.77 N (Tangential tooth on gear)

1. Weaker member is found to be gear

Lewis form factor for pinion (Y1) =0.12458

Lewis form factor for gear (Y2)=0.14488

AllowableStress1* Y1>AllowableStress2*Y2

So weaker member is gear, hence design data of gear is selected

2. Design of Gear

Ft2=Mt*Cs/r (where Mt is moment ,Cs is Service factor,r is radius)

=9550× power ×service factor/n*r (n is number of revolutions per second,r is pitch circle radius)

= r=r2 (r2 is pitch circle radius of gear)

= r2= 50m (where m is module)

= Cs is taken as 1.5 (medium shock 8-10 hrs daily)

= Ft2= 18486.31/m….(i)

Using Lewis Equation for Tangential Tooth Load

Ft2 = AllowableStress2 × b × P × Y2 × Kv (Where AS2 is Allowable stress of Gear material,b is tooth thickness,P is Circular Pitch, Y2 is Lewis form factor of Gear material,Kv is Velocity Factor)

= b=10m, P=pi*m (pi is 3.1428)
= Ft2 = 138 × 10m × pi*m × 0.14488 × Kv
= Ft2 = 628.11*m^2 * Kv…(ii)

Equating…(i) & ...(ii) ,we get..

628.11*m^2 *Kv = 18486.31/m

By trial and error we get:- m = 5 (module) , Vm = 8.115 m/s (Linear Velocity) , Kv = 0.3567 (Velocity Factor)

Check For Stresses :

Allowable Stress = AllowableStress2 * Kv...(iii)

Induced Stress = Ft2/b*Y2*P…(iv) (Taking m=5 ,Y2=0.3567)

Allowable stress = 49.2 MPa

Induced Stress = 32.48 MPa

°.° Allowable Stress > Induced Stress

Therefore, Design is safe

To Avoid breakage of gear

Effective Force , Feff = Ft2/Kv = 3696.77/0.3567

Feff = 10363.24 KN

Bending Strength of weaker part

Fb2 = AllowableStress2 × b × Y2 × P

Fb2 = 138 × 10 × 5 × 0.14488 × pi × 5

Fb2 = 15702.8 N

Fb2 > Feff , Design is Safe

Fos = Fb2/Feff = 15702.8/10363.24 = 1.515

3. Dimensions we get from theoretical Analysis

Module (m) = 5
Addendum (ha) = 1m = 1 × 5 = 5mm
Deddendum (hf) =1.25m = 1.25 × 5 = 6.25mm
Tooth thickness = pi * m/2 = 7.854mm
PCD pinion = 155mm
PCD gear = 500mm
ACD pinion = 165mm
ACD gear = 510mm
DCD pinion = 142.5mm
DCD gear = 487.5mm
Centre Distance (a) = 327.5mm
Base Circle Diameter pinion = 145.65mm
Base Circle Diameter gear = 469.84mm

Considering Dynamic load we get surface hardness of pinion as 350BHN and for gear as 300BHN

3D Modelling in AUTOCAD using data obtained from Theoretical Analysis

Dimensions obtained from Theoretical Analysis of material from data given (C-45 Steel) is used to model the design in AUTOCAD

3D Static Structural And Thermal transient Analysis in ANSYS of designed Model using material of data given and materials of Proposed SETS

Material of data given is C-45 Steel & Cast Steel 0.2% C and Material of Proposed SETS are : SET-1: C55Mn75 & C55Mn75, SET-2 : Carbon Fibre & S-Glass, SET-3 : Low Alloy Steel & Brass

III. MODELING AND ANALYSIS

MODELLING IN AUTOCAD

(i) Draw PCD, Addendum circle diameter , Dedendum circle diameter, and base circle diameter of pinion as per the values obtained from theoretical analysis**(ii)**PCD = 155 mm , Addendum circle diameter = 165 mm, dedendum circle diameter = 142.5 mm , base circle diameter = 145.65 mm**(iii)**Take one point on pitch circle draw one circle taking tooth thickness (7.854 mm)as radius mark the points that circle cuts on pitch circle and trim rest of the part**(iv)**Now there are three points on the pitch circle take middle point as centre and cut arc of radius equal to circular pitch (15.708mm) ^{2}on base circle on left side mark the point and with same radius taking the point on the base circle as centre cut the arc on right side such that it passes through all four circles, the obtained arc extending from addendum to deddendum circle is one of the two curves of the gear tooth.**(v)**There were three points initially on pitch circle , and middle point was taken as centre ,now take left point as centre and cut arc whose radius is equal to circular pitch on right side mark the point , taking this point as centre and radius equal to circular pitch cut arc on left side such that it passes through all four circles , the obtained arc extending from addendum to deddendum circle is second curve of the gear tooth.**(vi)**The distance between these two arcs on tip circle is the topland width**(vii)**Leaving tooth curves ,topland width and four circles trim the unnecessary points & arcs**(ix)**Drag the cursor near the teeth on deddendum circle of length equal to fillet radius to give fillet radius **(x)** The gear teeth is obtained ,right click on the teeth and drag the cursor to repeat the number of teeths required (Z1=31,number of teeths on pinion)**(xi)**On Z axis at a distance equal to face width copy the same 2D figure of gear and join the corresponding circumference points of both figures to obtain 3D figure of gear (Pinion)**(xii)**Similarly for gear[(Z2=100) same module = 5mm] the design can be obtained

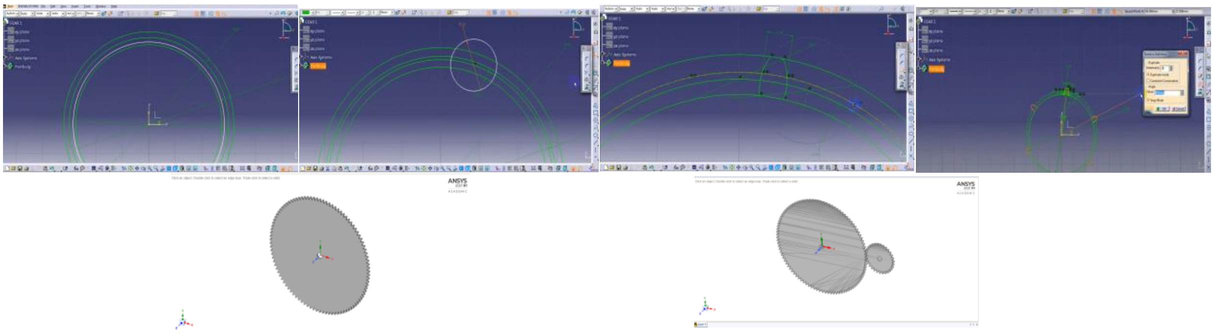

Figure 1: 3D Modelling Of Spur gear in AUTOCAD

GIVEN MATERIAL PROPERTIES

Material	Density (g/cm3)	UTS (MPa)	YS (MPa)	Thermal conductivity (W/m.K)	Specific Heat (J/Kg.K)
C-45	7.87	565	310	40-45	460-480
Cast Steel	7.86	550	380	54	490

PROPOSED MATERIALS

Material	Density (g/cm3)	UTS (MPa)	YS (MPa)	Thermal conductivity (W/m.K)	Specific Heat (J/Kg.K)
C55Mn75	7.858	660	460	21-52	470-520

C55Mn75: Steel is the best preferred material for making gears especially medium carbon steel. Balances ductility and strength and has good wear resistance & used for large parts ,forging and automotive components. Manganese content in this increases its resistance against wear and also increases its hardenability

CARBON FIBER: It is preferred for making light weight components due to its low density and also for making components working at critical conditions. carbon fibers have several advantages including high stiffness, high tensile strength, low weight to strength ratio, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports.

S-GLASS: E-Glass has been used extensively in polymer matrix composites, commonly termed “fibreglass”. These materials exhibit good mechanical properties, however, these have not been sufficient in some instances.

Consequently, the E-glass composition has been modified to produce more desirable properties. A higher stiffness material resulting from this is S-Glass.

Material	Density (g/cm3)	UTS (MPa)	YS (MPa)	Thermal conductivity (W/m.K)	Specific Heat (J/Kg.K)
Carbon Fibre(230G Pa)	1.8	2900	NA	21-180	900-1000
S-Glass	2.5	4750	NA	1.2-1.35	735-740

Brass C37700: Brass is an alloy mainly consisting of copper and zinc. Brass alloys can be easily shaped and are available in various colors. Brass has high thermal conductivity. UNS C37700 forging brass alloys have good forgeability. They are available in the form of rod.

Low Alloy Steel: A low-alloy steel is a type of metal mixture composed of steel and another metals that possess desirable properties. Low-alloy steel contains about 1%-5% of alloying elements. Therefore, it possesses precise chemical compositions that provide better mechanical properties that are intended to prevent corrosion.

Material	Density (g/cm3)	UTS (MPa)	YS (MPa)	Thermal conductivity (W/m.K)	Specific Heat (J/Kg.K)
Low Alloy Steel	7.85	1170	1070	41.8	NA
Brass C37700	8.442	460	140	NA	NA

ANALYSIS IN ANSYS

a) FOR GIVEN MATERIALS (C-45 Steel & CAST Steel 0.2% Carbon)

STATIC STRUCTURAL : On meshing the gear and pinion in ANSYS and after applying given moments we get maximum Equivalent stress , maximum deformation & maximum principal stress as follows

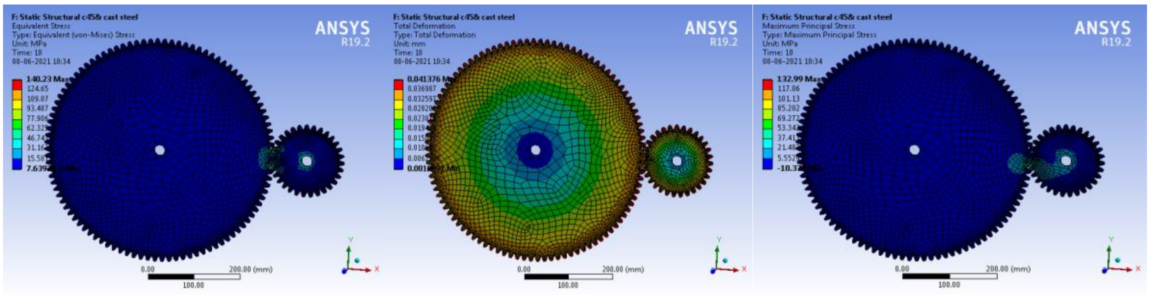

Figure 2 : Static Structural Analysis of Pinion (C-45 Steel) & Gear (Cast Steel 0.2 % Carbon)

THERMAL TRANSIENT : After Meshing gear tooth in thermal transient we get maximum Heat Flux and maximum Induced Temperature as follows

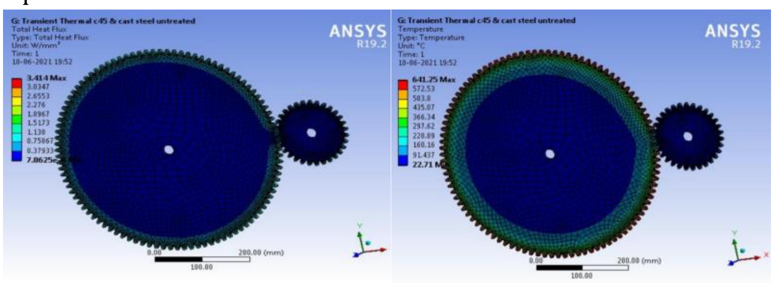

Figure 3 : Thermal Transient Analysis of Pinion (C-45 Steel) & Gear (Cast Steel 0.2 % Carbon)

b) FOR PROPOSED MATERIALS

1. FOR SET-1 (C55Mn75 & C55Mn75)

STATIC STRUCTURAL : On meshing the gear and pinion in ANSYS and after applying given moments we get maximum Equivalent stress , maximum deformation & maximum principal stress as follows

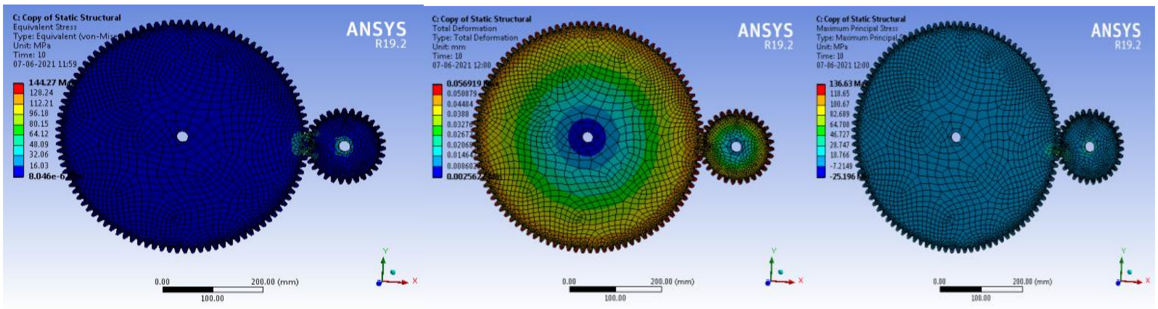

Figure 4 : Static Structural Analysis of Pinion (C55Mn75 Steel) & Gear(C55Mn75 Steel)

THERMAL TRANSIENT : After Meshing gear tooth in thermal transient we get maximum Heat Flux and maximum Induced Temperature as follows

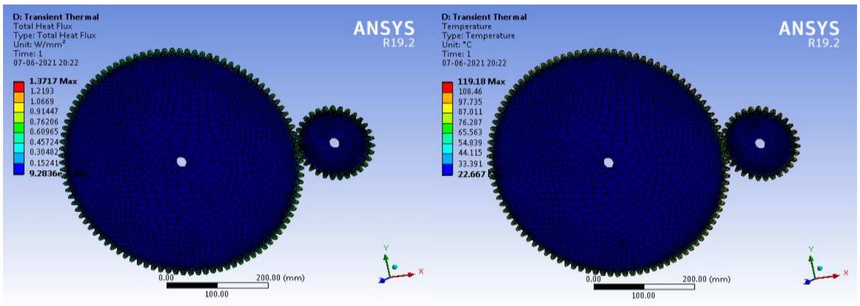

Figure 5 : Thermal Transient Analysis of Pinion (C55Mn75 Steel) & Gear(C55Mn75 Steel)

2. FOR SET-2 (CARBON FIBRE & S-GLASS)

STATIC STRUCTURAL : On meshing the gear and pinion in ANSYS and after applying given moments we get maximum Equivalent stress , maximum deformation & maximum principal stress as follows

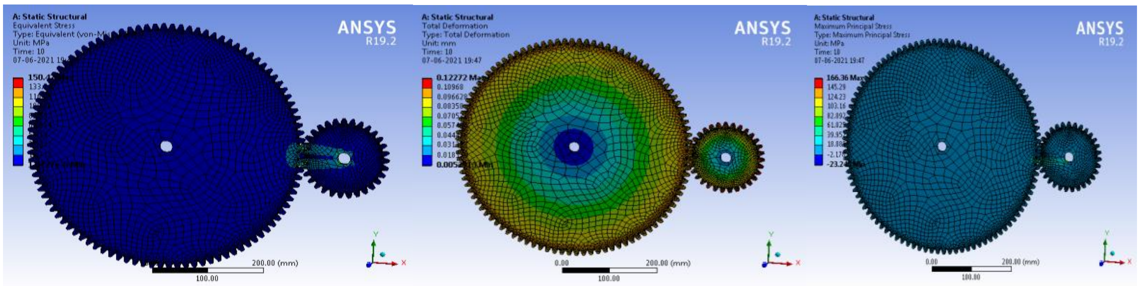

Figure 6 : Static Structural Analysis of Pinion (Carbon Fibre) & Gear(S-Glass)

THERMAL TRANSIENT : After Meshing gear tooth in thermal transient we get maximum Heat Flux and maximum Induced Temperature as follows

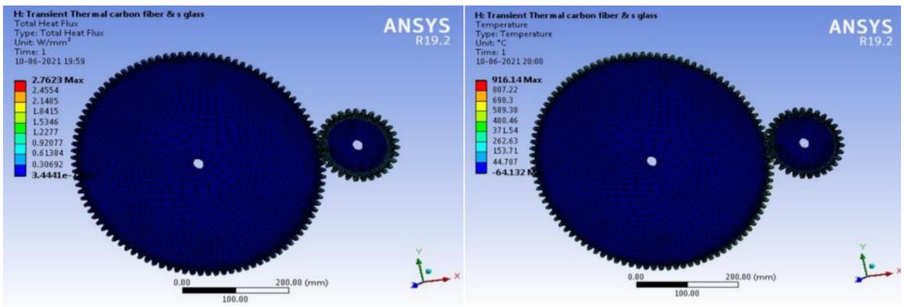

Figure 7 : Thermal Transient Analysis of Pinion (Carbon Fibre) & Gear(S-Glass)

3. FOR SET-3 (LOW ALLOY STEEL & BRASS)

STATIC STRUCTURAL : On meshing the gear and pinion in ANSYS and after applying given moments we get maximum Equivalent stress , maximum deformation & maximum principal stress as follows

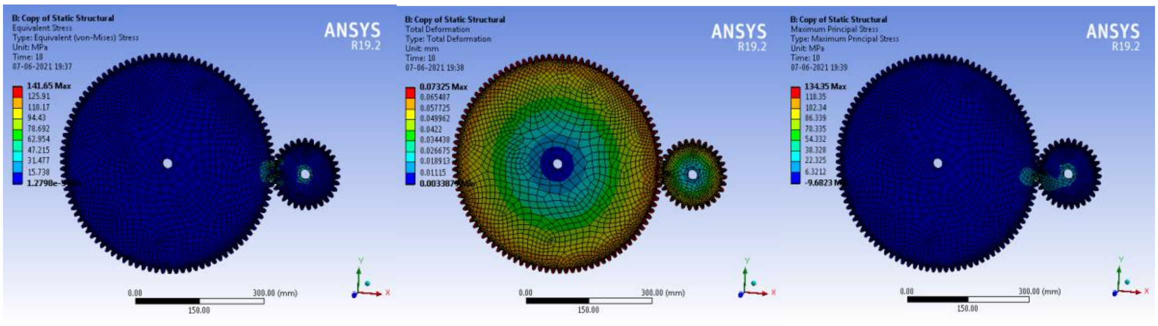

Figure 8 : Static Structural Analysis of Pinion (Low Alloy Steel) & Gear(Brass)

THERMAL TRANSIENT : After Meshing gear tooth in thermal transient we get maximum Heat Flux and maximum Induced Temperature as follows

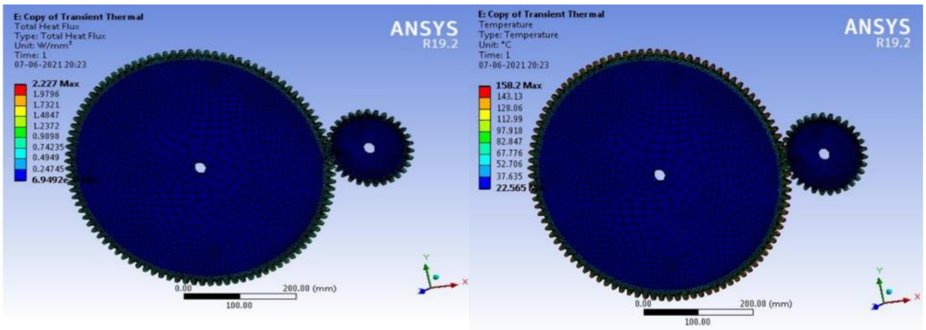

Figure 9 : Thermal Transient Analysis of Pinion (Low Alloy Steel) & Gear(Brass)

IV. RESULTS AND DISCUSSION

Case-1 : Analysis Using Material Of Given Data (Pinion : C-45 Steel , Gear : Cast Steel 0.2% Carbon)

Theoretical Allowable Stress1 = 207 MPa

Theoretical Allowable Stress2 = 138 Mpa

Maximum Equivalent Stress = 140.23 MPa

Maximum Deformation = 0.041376 mm

Maximum Principal Stress = 132.99 MPa

Maximum Heat Flux : 3.414W/mm^2

Maximum Temperature = 641.25 °C

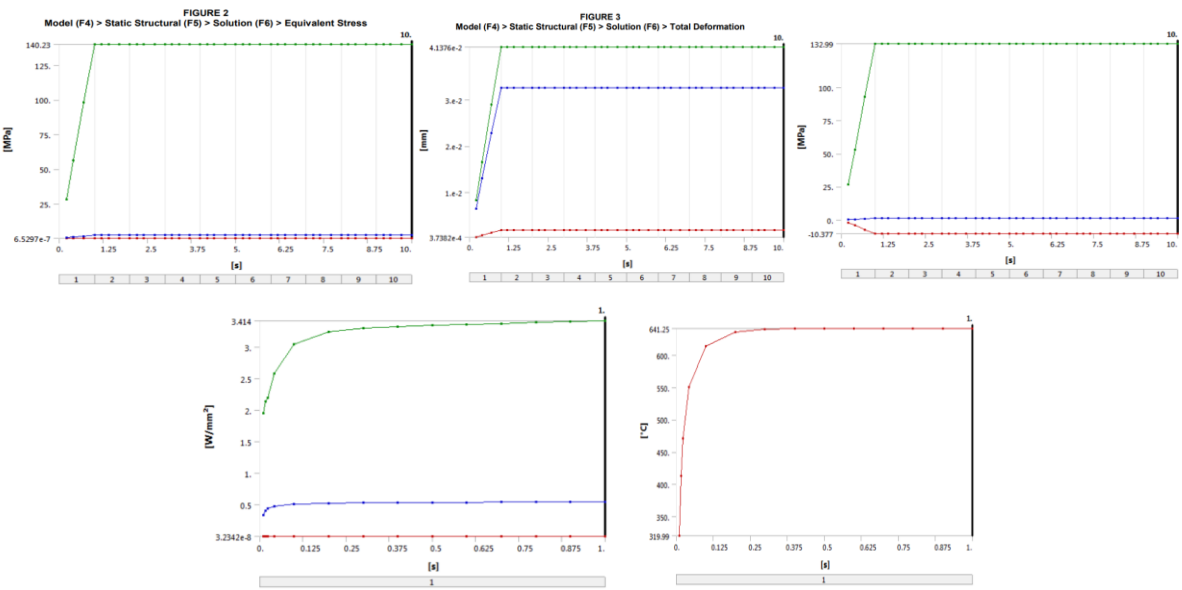

Chart-1 : stress, deformation,heat flux ,temperature , C-45 Steel & Cast Steel 0.2%C

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Theoretical Allowable Stress2 ~ Maximum Eqiuivalent Stress

In theoretical analysis weaker member is gear and Allowable stress for gear is 139 Mega Pascal approximately and in FEM Analysis through ANSYS Maximum Induced equivalent stress is 140 which is similar to that of theoretical Allowable stress.

Therefore design is safe as theoretical and FEM Analysis results through ANSYS are similar

Case 2 : Analysis Using Materials (Pinion : C55Mn75 Steel , Gear : C55Mn75 Steel)

Maximum Equivalent Stress = 144.27 MPa

Maximum Deformation = 0.056919 mm

Maximum Principal Stress = 136.63 MPa

Maximum Heat Flux : 1.3717W/mm^2

Maximum Temperature = 119.18 °C

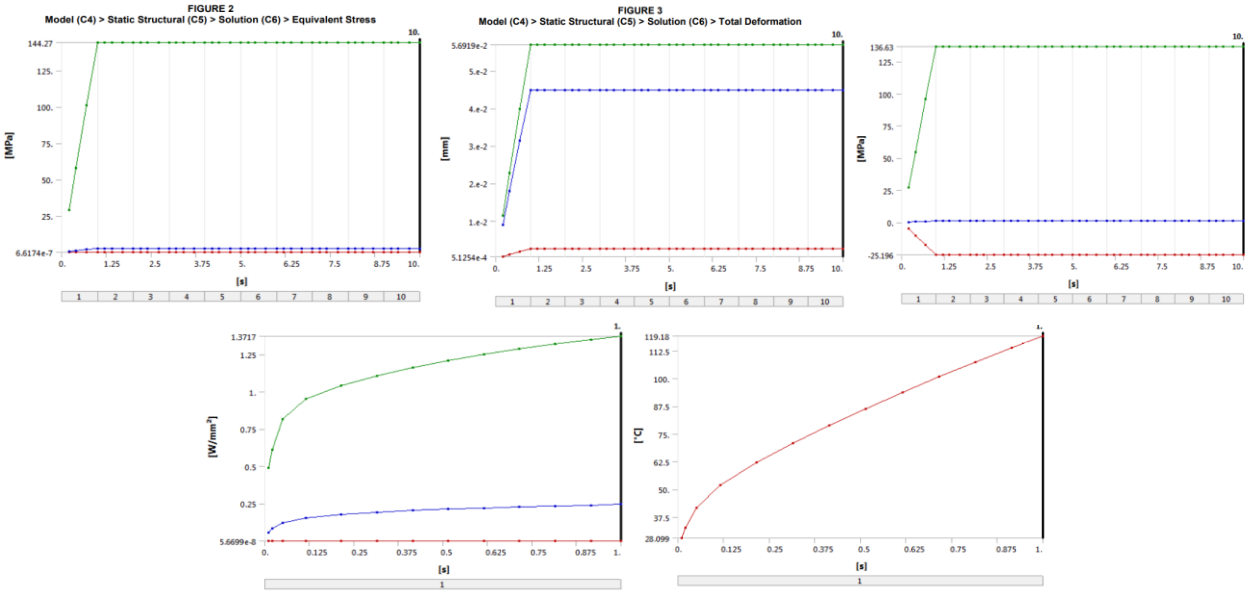


Chart-2 : Stress,deformation,Heat Flux,Temperature, C55Mn75 & C55Mn75

Case 3 : Analysis Using Materials (Pinion : Carbon Fibre , Gear : S-GLASS)

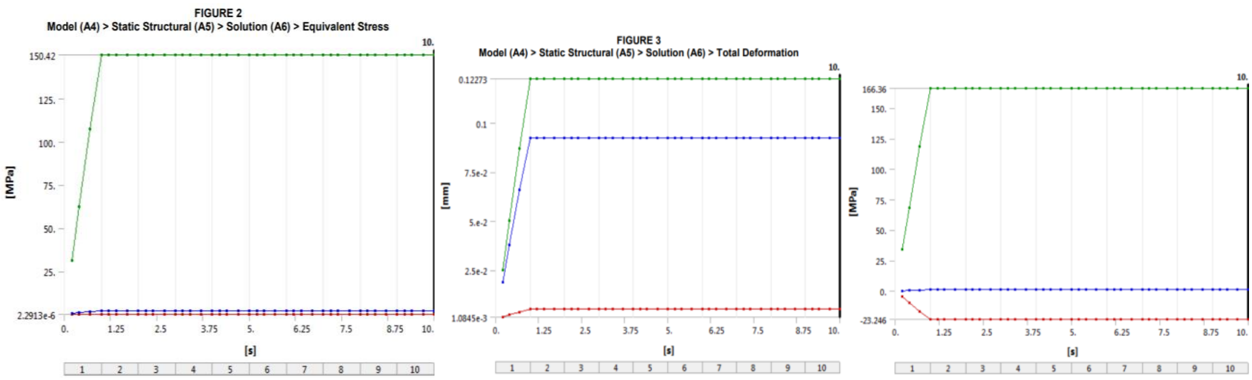
Maximum Equivalent Stress = 150.4 MPa

Maximum Deformation = 0.12272 mm

Maximum Principal Stress = 166.36 MPa

Maximum Heat Flux : 2.7623W/mm^2

Maximum Temperature = 919 °C



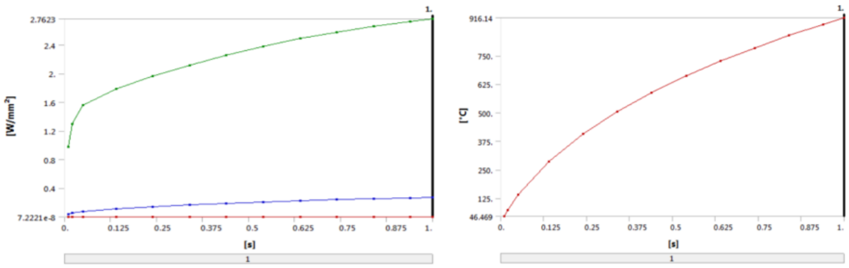


Chart-3 : Stress, deformation, Heat Flux, Temperature, Carbon Fibre & S-GLASS

Case 4 : Analysis Using Materials (Pinion : Low Alloy Steel , Gear : BRASS)

Maximum Equivalent Stress = 141.65 MPa

Maximum Deformation = 0.07325 mm

Maximum Principal Stress = 134.35 MPa

Maximum Heat Flux : 2.227W/mm^2

Maximum Temperature = 158.2 °C

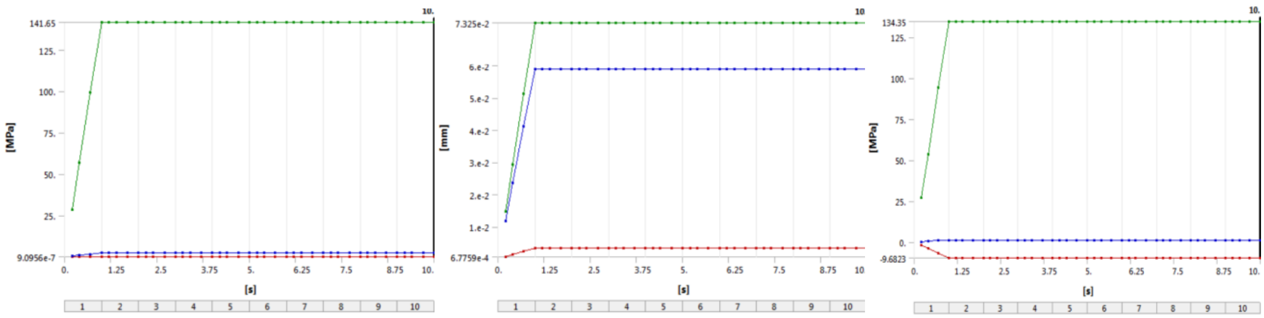


Chart-4 : Stress, deformation , Low Alloy Steel & Brass

COMPARISON OF MATERIALS ON THE BASIS OF MECHANICAL & THERMAL EFFECTS INDUCED

Table 1: Comparision of materials

PAIR OF MATERIALS	DEFORMATION INDUCED (mm)	EQUIVALENT STRESS (MPa)	MAXIMUM PRINCIPAL STRESS (MPa)	HEAT FLUX GENERATED (W/mm2)	MAXIMUM TEMPERATURE (degree Celsius)
C-45 & CAST STEEL 0.2 % C	0.041376	140.23	132.99	3.414	641
C55Mn75 & C55Mn75	0.056919	144.27	136.63	1.3717	119.18
CARBON FIBRE & S-GLASS	0.12272	150.4	166.36	2.7623	919
LOW ALLOY STEEL & BRASS C37700	0.07325	141.65	134.35	2.227	158.2

COMPARISON OF MATERIALS ON THE BASIS OF WEIGHT

Table 2 : Comparison Of Materials On The Basis Of Weight

PAIR OF GEAR MATERIALS	TOTAL WEIGHT(Kg)
C-45 & CAST STEEL 0.2 % C	13.175

C55Mn75 & C55Mn75	**13.157**
CARBON FIBRE & S-GLASS	**4.0901**
LOW ALLOY STEEL & BRASS C37700	**14.064**

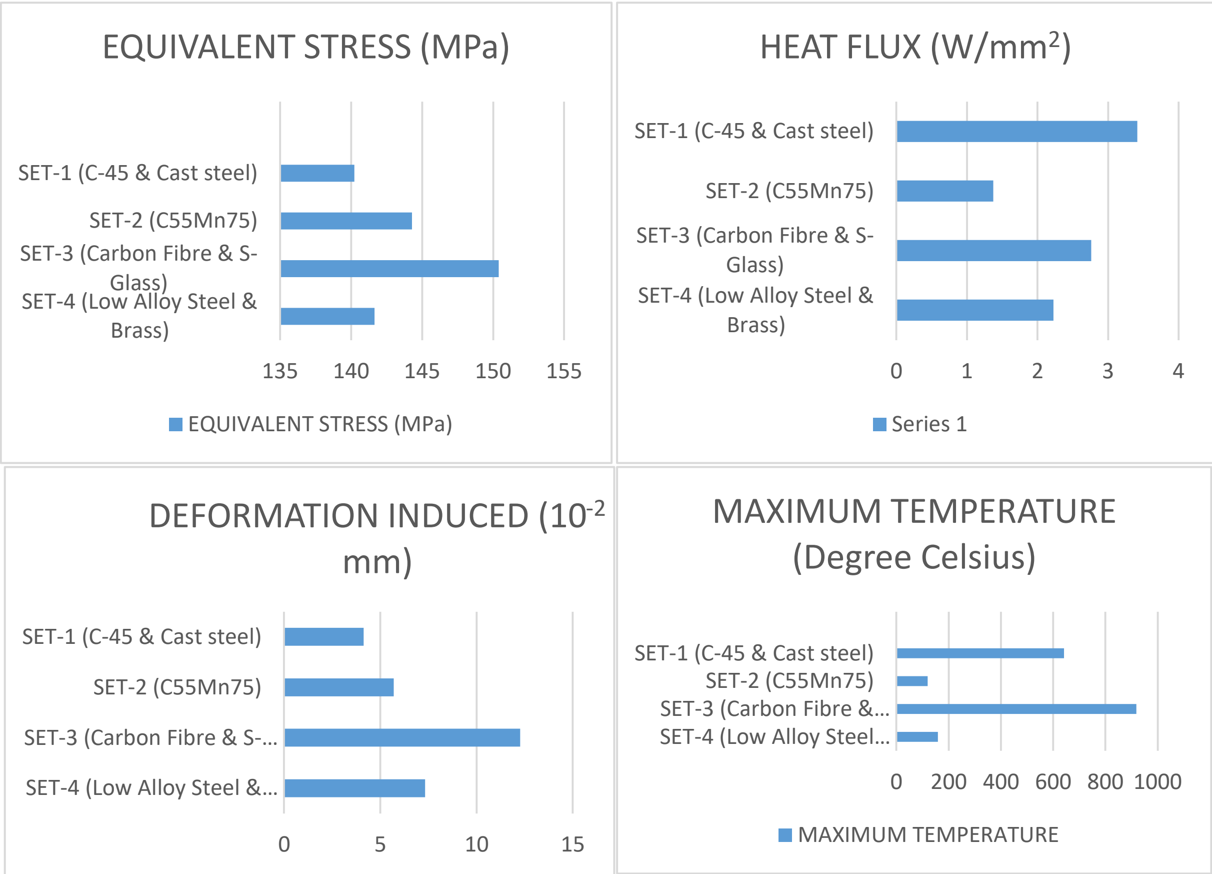


Chart-5 : Graphical Comparison Of Materials

V. CONCLUSION

From the above analysis deformation & equivalent Stresses in pair metals C-45 & CAST STEEL 0.2% C ,C55Mn75 & C55Mn75,CARBON FIBRE & S-GLASS ,LOW ALLOY STEEL & BRASS C37700 are (0.04mm,140) ,(0.05mm,144),(0.12mm,150) & (0.07mm ,141). Clearly C-45 & cast steel pair has least deformation and vonmisses stress so considering only mechanical properties C-45 & Cast Steel is the best set to be selected for design overall. Considering thermal affects C55Mn75 is found to be better for design due to less maximum temperature , less stresses & deformations induced & intermediate heat flux rate comparatively to all other metals. Comparing density carbon fibre & s-glass should be the best set for making light weight gears but deformations and stresses and temperature induced are large & heat flux rate is also less which make it highly undesirable . Also Fabrication Cost is less but C45 Pair & C55Mn75 Pair are equivalent in weight and other factors are safe but thermally C55Mn75 is much more desirable due to very less temperature induced comparatively which make it highly desirable design material for gears.

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