Finite Element Analysis and Optimization of Crank Shaft of Briquette Machine

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Abstract— The aim of this work is to analyze various failure modes occurred in crankshaft of Briquette machine subjected to cyclic loads and also to improve the overall design of the crankshaft. Finite Element Analysis provides variety range of solution in engineering industries. One among them is the analysis of Briquette machine – crank shaft. The real world problem going to solve state-of-art technology called FEA. Briquette machine used to compress the agricultural waste into high calorific solid fuel. When small particles of solid materials are pressed together to form coherent shapes of larger size, the process are termed briquette. Power from motor is used to rotate the flywheel. Crank shaft, connecting rod & Piston assembly converts the rotary motion into linear motion. Crank shaft is one of the major component plays important role of the operation of the machine. FEA used for validation, design improvement, fatigue life cycle calculation, and optimization of crank shaft. ANSYS finite element code used to solve the problem. This work investigates the fatigue analysis for various failure modes occurring in the briquette machine. 3D model of crankshaft as per the existing dimensions are created and the model is imported in FEA software. The driving force of the reciprocating members, vector and acceleration analysis are calculated by using analytical method. The parameters such as material properties, boundary conditions, mechanical properties, and load on reciprocating members are given as an input and results obtained from Ansys workbench software are analyzed at various failure modes. Finally, weak areas of failure are identified and corrected.

Keywords— FEA, Failure Model, Crank Shaft, Briquette Machine.

I. INTRODUCTION

The primary function of the crankshaft is to convert the translational mechanical energy of the piston being driven back and forth by the pneumatic energy provided by pressure change as a result of the combustion reaction. Crankshafts are high volume production engine components and their most common application is in an automobile engine. In an internal combustion engine, the piston reciprocating motion is linear and is converted into rotary motion through the crankshaft. There are many other applications of a crankshaft which range from small one cylinder engines to very large multi cylinder marine crankshafts. The connection of the piston to the crankshaft via the connector pin provides for the transfer of this energy; the force of the connector pin to the small portion of crankshaft axel that is offset from the main axis causes the rotation about the main axis of the crankshaft. The crankshaft is connected to the pull-start by the connection cup of pull-

start. When the pull-start chord is pulled, the transferred energy is converted to rotational energy of the crankshaft.

Now that the crankshaft has converted the translational mechanical energy of the piston to mechanical rotational energy, its next function is transferring this energy to the driver pulley of the pulley and belt system. This is a critical transfer of energy because it is the belt and pulley system that ultimately displaces this rotational mechanical energy to the auger, causing to rotate and collect the snow and other material that is imported by the auger. That the flow is associated with the crankshaft is just this energy conversion. The crankshaft located directly adjacent to the gas engine (two cycle), since it is connected to the piston by the connector pin. This location very next to the engine is a hot environment that is caused by the convection of thermal energy of the engine blocks as heat sink. The high temperatures environment are cause for consideration when choosing the material for the crankshaft, which will be discussed by many of the analysis in the following section, along with the appearance and geometry of the component [1-3]. Engine pistons are one of the most complex components among all automotive components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. The pistons form the bottom half of the combustion chamber and transmits the force of combustion through the wrist pin and connecting rod to the crankshaft. Piston failures arise due to many reasons: mechanical stresses; wear mechanisms; thermal stresses; oxidation mechanisms; temperature degradation; etc. Fatigue is a source of piston and inner liner damages. Although, traditionally these damages are attributed to wear and lubrication sources, fatigue is responsible for a larger damages such as piston damages and some damages where the main cause is attributed to wear and/or lubrication mechanisms may have in the root cause origin a fatigue crack [4-5].

Crankshaft is one of the largest components in the internal combustion engine that has a complex geometry consisting of cylinders as bearings, plates as the crank webs and balancing mass. Section geometry changes in the crankshaft cause stress concentration at fillet areas where bearings are connected to the webs of the crank. In addition, these component experiences both bending and torsional load during its life service. Therefore, areas of filleted portion are locations that experience the most critical stresses during the service life of

the crankshaft. Resultants of these locations are main sections of fatigue failure of the component. Size of the crankshaft depends on the number of cylinders and horsepower output of the engine. The size of the crankshaft could 3.2 kg from range for a single cylinder engine with the 12 hp output power to 300 tons for a fourteen cylinder diesel engine with 108,920 hp output power. In an IC engine, two load sources apply force on the crankshaft during combustion. The applied load during combustion in the combustion chamber to the piston is transmitted to the crankpin bearing by a four bar mechanism (slider-crank). The other load source is due to dynamic nature of the slider-crank mechanism. At high speeds operations of the engine, the centrifugal forces are present at different rotating components like connecting rods. These load sources apply both bending and torsional load on the crankshaft. The classification of the cause of journal bearing failure or damage to three possible sources; "(a) operating sources such as, high operating oil temperature, defective lubrication of journals, oil absence on carter, improper use of the engine (over-revving); (b) mechanical sources such as misalignments of the crankshaft on 18 the assembling, improper (wrong size) journal bearings, no control on the clearance size between journals and bearings, crankshaft vibration are the major cases; (c) repairing techniques such as misalignments of the journals, misalignments of the crankshaft, high stress concentrations, high surface roughness (due to origination of wearing, improper grinding), nitruration, improper welding or defective grinding, straightening operation,." Other than these common failures in the crankshafts is mechanical crack nucleation at the fillet radius of journal bearings. There are different criteria are used for crack identifying in the fillet area the relationship of different failure modes such as stiffness change, surface cracks, and two-piece failures on different crankshafts [6].

A. Crankshaft Failures Common Causes

Loss of effective lubrication is due to contaminated lube oil, poor quality, failed lube oil pumps or incorrect specification lube oil. Over speeding of engines, or long term operation in a critical or forbidden revolution range. Faulty crankshaft detuned or damper, designed to remove vibration excessively from the crankshaft. Failure of operation can lead to excessive crankshaft vibration and fatigue. Engine power imbalance leading to cyclic loading, fatigue failure. This can be caused by poor maintenance or monitoring of engine power, or even poor quality fuel. Hydraulic locking of cylinders, flooding of cylinders with cooled water. Bearing misalignment can be detected early with proper crankshaft deflection measurement [6-7].

B. Design Failures

Design faults, a common problem as more licenses are passed out to new shipyards. Incorrect or blatant ignorance of the material compositions or poor manufacture of crankshaft can lead to early failure. Overloading of engine. For propulsion grounding, machinery, and/or fouling of the propeller. It is most essential that crankshafts are manufactured using suitable materials. They are machined to

proper standard to avoid stress raisers leading to high areas of stress and potential points of failure [6-9].

II. BRIQUETTE MACHINE

Every year millions of tons of agriculture and forest residues are generated. There are so many natural resources in that biomass also includes agro industrial bi-products and animal refuse. This constitute tremendous waste problem in spite of their known high energy potential.

These problems is compounded by the irregular size, low density, volumes, collection, handling and transportation of the material, currently both storage and disposal and only add to cost and hence affect productivity and profitability, and hence the ideal transfer is to convert different kinds of waste into high density, high value "Solid fuel" – Briquettes.

When small particles of solid materials are pressed together to form coherent shapes of larger size, the process is termed briquetting. Fig. -1 shows schematic sketch of Briquette Machine. The Materials such as tremendous, saw dust, wood chips, ground nut shells, rise husks, cotton stalk, baggage, pine needles, corn waste, coconut shells, coffee bean husks, bark cardboard waste, textile waste, corrugated paper, mews paper and packing waste. can be converted into profitable solid fuel Briquettes. They have a high calorific value. Briquettes burn evenly and steadily giving a longer lasting fire. They have low ash content. This means no pollution of the environment and longer life for your machinery. They are cheaper and more efficient source of energy being substantially less in volume, you save by way of transport and storage costs. They are clean and easy to store, even over extended periods and have a practically unlimited life span. You save costs incurred on disposal are storage of waste material. Farmers, agricultures, owners of saw mill, paper mills, and sugar and textile mills, rice mills manufacturing units of entrepreneur in small towns, where ever waste material is generated in plenty.

For domestic purpose cooking in homes, we can use existing or improved wood burning stoves. Water or iron box heating purpose also we can use briquette. In addition to use in the house, Briquettes can also be used in restaurants, hotels, hospitals, bakeries, and army kitchens. Use as fuel for industrial boilers, Vanaspathy, oil extraction units, paper mills, chemical plants and dyeing houses. They can also be used in ceramic units, brick, kilns, in Tea estates and in local small scale industries such as bakeries potteries, drying of vegetables, spices, etc. Briquettes because of uniform properties are also an ideal alternative for use in gasified producer units. Binder less Briquetting volumes waste material is efficiently and economically converted into compact briquette disc without the addition of a binding agent provided the particle size and moisture content of the material are with certain specific limits.

Fig. 1 Briquette Machine

III. FINITE ELEMENT METHOD

The finite element method is a numerical technique, well suited to digital computers, which can be applied to solve problems in solid mechanics, fluid mechanics, heat transfer and vibrations. The procedure to solve problems in each of these fields is similar; however this discussion will address the application of finite element methods to solid mechanics problems. In all finite element models the domain (the solid in solid mechanics problems) is divided into a finite number of elements. These elements are connected at points called nodes. In solid models, displacements in each element are directly related to the nodal displacements. The nodal displacements are then related to the strains and stresses in the elements. The finite element method tries to choose the nodal displacements so that the stresses are in equilibrium (approximately) with the applied loads. The nodal displacements must also be consistent with any constraints on the motion of the structure.

The finite element method converts the conditions of equilibrium into a set of linear algebraic equations for the nodal displacements. Once the equations are solved, one can find the actual strains and stresses in all the elements. By breaking the structure into a larger number of elements, the stresses become closer to achieving equilibrium with the applied loads. Therefore an important concept in the use of finite element methods is that, in general, a finite element model approaches the true solution to the problem only as the element density is increased.

IV. FEA IN CRANKSHAFT

ANSYS is a general purpose finite element modeling package for numerically solving a wide variety of problems like in the field of mechanical, aeronautical, automobile, etc. All these application oriented problems include, such as static or dynamic structural analysis on linear and non-linear, fluid and heat transfer problems, also includes electromagnetic and acoustic problems.

ANSYS is finite element analysis software which enables engineers to perform several tasks, those are as follows: Models Building in computer or CAD models transfer of structures, components, products, or systems. Applying design performance conditions and operating loads. Physical responses study, such as temperature distributions, stress levels and electromagnetic fields. Design optimizations early in the development process to costs reduced production. Prototypes testing in environment where it is impossible or undesirable for example, most sensitive analysis like biomedical applications. Crankshaft is analyzed in finite element analysis by dynamic analysis. FEA consists of a computer model of a material or design that is analyzed on various for specific results. FEA is used in new product design, development for existing product refinement as per current requirement. If there is any modification requires an existing product or structure is can be optimized and utilized to qualify the product or analysis on structure can be made for a new service condition. For all case of structural failures FEA may be suitable to determine the design modifications to meet the required new condition. Linear systems are bit complex and it is generally not taking into account for plastic deformation. Nonlinear systems, account for plastic deformation, and also are capable of material testing in all the way to fracture.

In FEA for all complex system are marked as points called nodes, all together formed to make a grid called a mesh. Mesh is programmed to contain the physical properties of the material and a structural property which is defined how structure will react to certain applied loading conditions at the end. Nodal surfaces and volume are assigned at a certain density throughout the material. It is depending on the anticipated levels of stress at a particular area or regions, which will receive some particular amount of applied stress usually, have a higher nodal density than those which experience little/no stress. In the point of interest may consist of fracture point of previously tested material, fillets, complex detail, corners and high stress areas. Designed material mesh acts like a spider web from each node, they extends a mesh element to all other of the adjacent node points. This vector web carries the material physical, thermal, electrical and electromagnetic properties to the object.
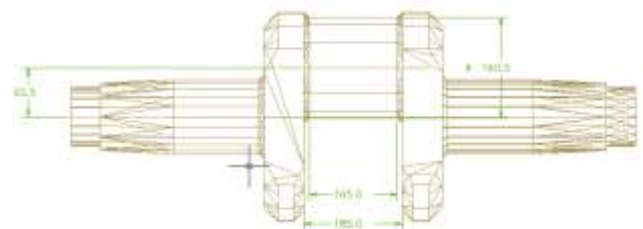
C. Modeling

Fig. 2 2D model of crankshaft

3D model of crankshaft is created by using Unigraphics software. The model consists of different volumes such as cones; cylinders which are joined together by using unite options. The different volumes are assembled together to make a solid 3D model as shown in Fig. 2.

TABLE I

PROPERTIES OF EN 24

Properties	Values
Density	7.85×10^{-6} kg/mm^3
Young's Modulus	2.1×10^5 N/mm^2
Poisson's ratio	0.28

D. Boundary Condition and Meshing

Higher order Element
Element size   = 12mm
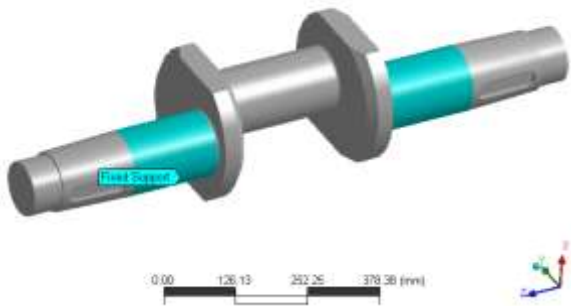Total number of elements   = 33789
Total number of nodes   = 108104

Fig. 3 Boundary conditions applied on both sides

Fig. 4 Meshed model of crankshaft

E. Force Applied

Fig. 5 Operational load (Force) applied on Crank pin – Forward Stroke
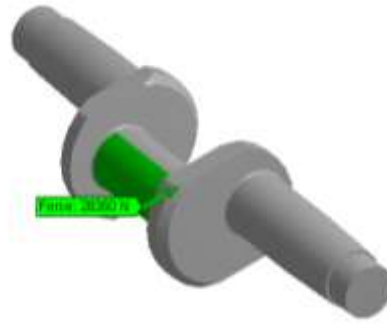
Fig. 6 Force applied on Crank pin – Reverse Stroke
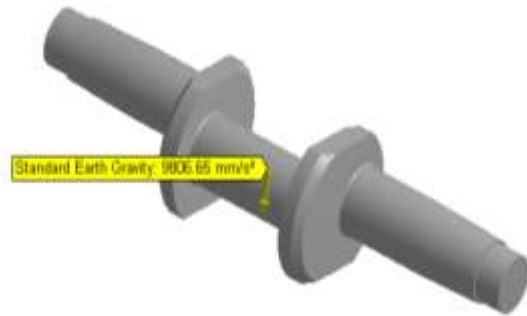
Fig. 7 Standard Earth Gravity

V. DRIVING FORCE CALCULATION
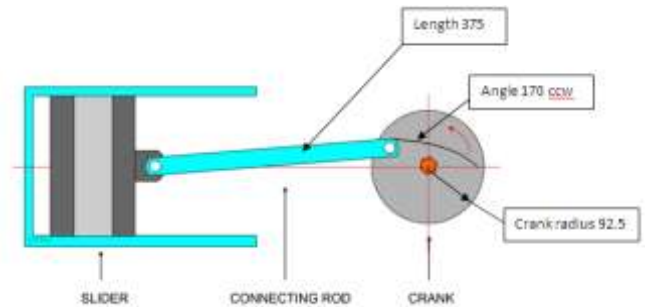
Fig. 8 Slider Crank Mechanism

Fig. -8. Shows the basic slider crank mechanism of a reciprocating mass. The parameters of the Mechanism are listed below

Speed of the crank   = 210 rpm
Density of material   = 7.8 x10-6 kg/mm3
Length of the connecting rod   = 375 mm
Crank radius   = 92.5 mm
Angle θ   = 10º
Angular velocity ω   = 2ΠN / 60
 Where,
N = speed of crank, rpm

Velocity analysis   n = l/r = 0.375/0.0925 = 4
Where,
N = ratio of length of connecting rod to crank radius (l/r)

Velocity of the slider   Vp = r. ω. [sinθ + sin 2θ/n]

$\qquad$ Vp = 0.4 m/s

Where,

ω = angular velocity, rad/sec

N = speed of crank, rpm

r = crank radius, mm

F. Acceleration analysis:

Acceleration of the slider a_p= ω2.r. [cosθ + cos2θ/n]

$\qquad a_p$ = 54 m/s^2

Volume of crankshaft	= 24.64 x 10^6 mm^3
Mass of the crankshaft	= 192 kg
Mass of the connecting rod	= 48 kg
Mass of the fly wheel (2Nos.)	= 1536.6 kg
Volume of the piston	= 19.43 x 10^{-6} mm^3
Mass of the piston	= 150 kg

G. Total mass of reciprocating members:

Mass of [crankshaft + connt. rod + fly wheel + piston]

$\qquad$ = 1926.60 kg = 18900 N

Driving force $\qquad$ = 18900*54 = 1020 KN

Therefore, Load acting on reciprocating members is 102 tonnes. Considering factor of safety 1.5 times, the load is 1.53 X10^6 N.

VI. SHAPE OPTIMIZATION

The process of shape optimization is changing the physical dimensions of a part structural to reduce weight, machining within the design constraints of the industry, mostly optimization may be made for maximum stress or minimizing the deflection. Shape optimization can include, optimizing shape factors such as hole diameter, fillet radius and height or width of a part. The shape optimization is performed on solid models also applied many applications for surface models like shells. In other terms optimization is the changing a structure's physical properties, such as area, moment of inertia, thickness, etc. [10]

During analysis the following steps are involved

a) Analysis Parameter

1. Material properties
2. Cyclic load
3. Boundary condition (How to fix the shaft to simulate real case)
4. S-N curve
5. 3D model of the part

b) Results to be predicted:

1. Von-Mises Stress
2. Shear stress
3. Alternate & Mean Stress
4. Deflection
5. Weak areas
6. Possible design improvements
7. Fatigue calculation

There is few improvement trials has been involved with various parameters, the following Fig. 8 shows the initial crank web thickness of 45 mm.
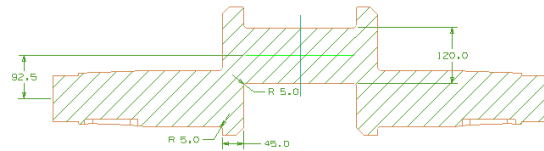

Fig. 9 Initial Crank web thickness 45mm (improvement-1)

The results from the initial trial with crank web thickness of 45 mm were failed due to lack of web thickness. So subsequent trials made with improvement 2 & 3 varying the dimensional parameters, which is also failed, finally improvement 4 with web 65mm + Blend 5mm to 10mm+ 150mm pin diameter, the designed drawings and its dimensions are results as shown Fig. 9-12.
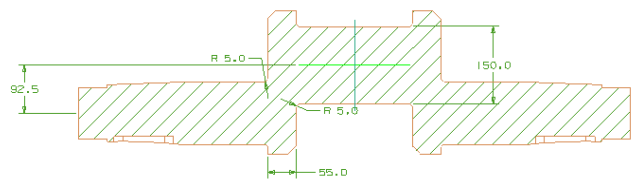

Fig. 10 Web Thickness 55mm + Pin diameter increased from 120mm to 150mm (improvement-2)
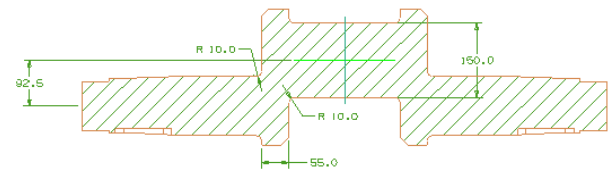

Fig. 11 Web Thickness 55mm + Pin diameter increased from 120mm to 150mm + Radius increased from 5mm to 10mm (improvement-3)
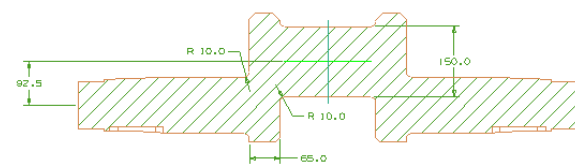

Fig. 12 Web Thickness 65mm + Pin diameter increased from 120mm to 150mm + Radius increased from 5mm to 10mm (improvement-4)
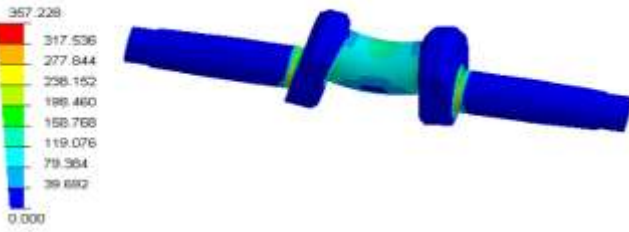
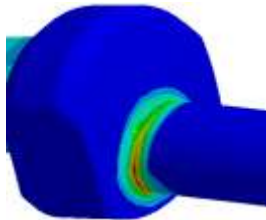Fig. 13 Stress for load-1 (Improvement -4)

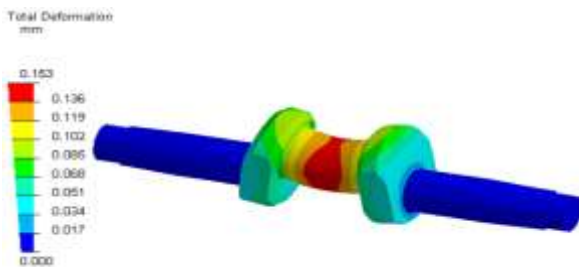Fig. 14 Stress for load-1 (Improvement -4)-Weak area

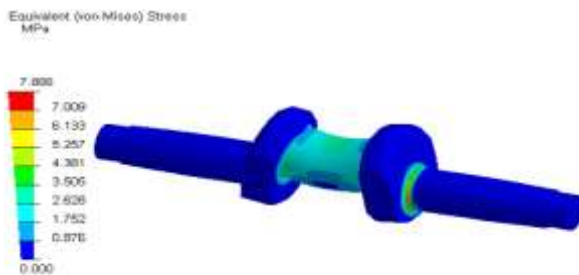Fig. 15 Deformation for load1 (Improvement -4)
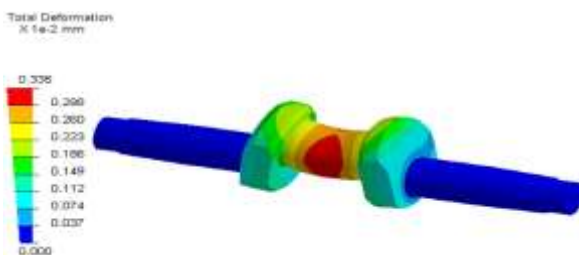

Fig. 16 Stress for load-2 (Improvement -4)

Fig. 17 Deformation for load 2 (Improvement -4)

Fig. 13-19 shows the results of shaped optimized improved results at the end of improvement 4. Fig. 20 shows the Goodman's Curve of consolidated graph.

TABLE II

CONSOLIDATED SHAPE OPTIMIZATION INFERENCE TABLE

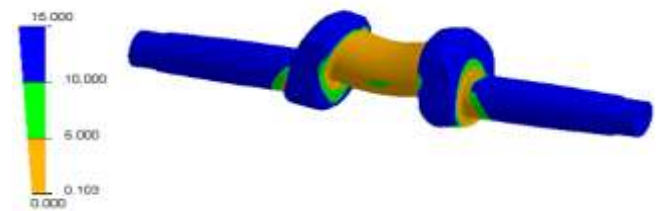| Design Stages	Initial design	Imp-1	Imp-2	Imp-3	Imp-4
Max Stress N/mm^2	710	651	576	513	357
Min Stress N/mm^2	13	12	11	11	8
Mean Stress N/mm^2	361.5	331.5	293.5	262	182.5
Alt. Stress N/mm^2	348.5	319.5	282.5	251	174.5
Design Paramet -ers	Web thickn -ess 45mm	Web 55 mm	Web55 + Blend 5mm+ 150mm pin diameter	Web55 + Blend 5mm to 10mm+ 150mm pin diameter	Web65 + Blend 5mm to 10mm+ 150mm pin diameter
Infer -ence	Not Ok	Not Ok	Not Ok	Not Ok	Ok

Fig -18: Fatigue Safety Factor (Improvement -4)
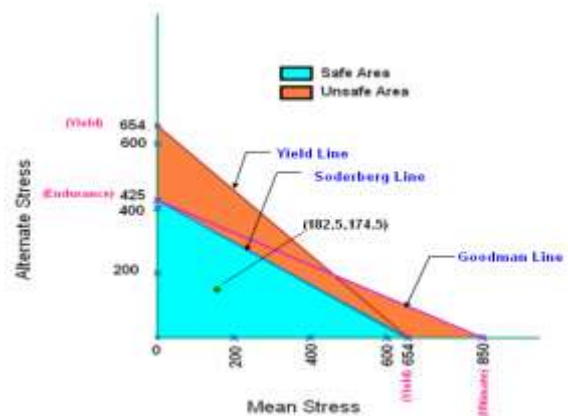

Fig -19: Goodman's Curve- Improvement -4

Fig -20: Goodman's Curve- Consolidated Graph

VII.   CONCLUSIONS

FEA performed with various parameters of crank shaft. Shape optimization is the major criteria of the improvement. Various different modifications performed in the shape optimization of the crank shaft. The induced stress, weak area, deformation and fatigue life are noticed for all the modifications.

Crank shaft web thickness and blend radius plays important role of improvement design. Improvements are well noticed for all the cases. Material En-24 is a high quality, high tensile alloy steel having high strength, ductility and toughness. It is available in the round, bar and Plate. Round is used to design the crank shaft. EN-24 material, 65mm web thickness, 10mm blend radius and 150mm pin diameter design is concluded as the optimized design. In the other view of improvement, FEA for fabrication with IS 2062- Structural steel material may also be performed. The induced stress is more than yield stress of the material. So the design is unsafe is not recommended.

In the view of future improvement, forged material with high strength capabilities can be performed to reduce the material cost and manufacturing cost furthermore.

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