ANALYSIS OF MECHANICAL AND THERMAL STRESSES ON CONNECTING ROD/PISTON OF A VARIABLE COMPRESSION RATIO ENGINE POWERED BY BIODIESEL

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Abstract - Use of alternative fuels in internal combustion engines has become a prime interest for researchers and industrialists as the conventional fuels continue to have higher costs and bigger impact on the environment. However, not too many research works address the analysis of mechanical and thermal stresses in essential components of engines running on alternative fuels. In this work, the fairly new engine technology, Variable Compression Ratio, powered by the alternative fuel biodiesel is considered in terms of the analysis of mechanical and thermal stresses on the connecting rod/piston. Modelling the performance of a biodiesel-powered VCR engine using available software in addition to the modelling the stresses induced on the piston/connecting rod for a variable stroke engine powered by biodiesel using finite element analysis (FEA) software is presented in this work. Experimental work was carried out where biodiesel was injected in a diesel engine and the values of the power and torque were monitored using appropriate measuring devices. Verification of the work was then carried out using special software (Diesel RK) by simulating the same test with similar engine specifications and engine conditions. Temperature and pressure values where then obtained from DieselRK and applied as boundary conditions in the finite element analysis simulation on the piston and connecting rod. Results showed that using biodiesel fuel increases both the mechanical and thermal stresses in the piston and connecting rod at an earlier stage of the engine stroke due to the characteristics of biodiesel when compared to diesel fuel; this increase in stresses reduces the lifetime of the piston and connecting rod which affects the engine on the long run. Furthermore, an increase in compression ratios results in higher values of stress for both types of fuel. These are significant findings for the industry which indicate that modifications to the engine operation are necessary to reduce stresses on these main engine components.

Keywords - Biodiesel, Modelling, Variable Compression Ration, stresses, Finite Element Analysis

I. INTRODUCTION

Showing the mechanical and thermal stresses of some parts of the diesel engine powered by biodiesel fuel as an alternative fuel with the use of the variable compression ratio (VCR) technology has not been reported before. This work combines new engine technology; VCR with new alternative fuel Biodiesel along with the study of the stresses induced in some of the engine parts, the piston and the connecting rod. One of the justifications of doing this research is to investigate the thermal and mechanical stresses of the piston and connecting rod by using an alternative fuel such as biodiesel fuel in a diesel engine, and comparing those stresses results with the stresses induced form diesel fuel on the same engine. Considering all the current issues related to the use of fossil fuels, attention to biodiesel as an alternative fuel has been brought forefront recently; It is renewable, available everywhere and has proved to be a cleaner fuel and more environment friendly than fossil fuels(Sureshkumar, el at., (2008)), (Agarwal and Rajamanoharan, (2009)).

Another justification to this work is to investigate the effect of using VCR technology on such engines that are powered by biodiesel fuel. VCR is gaining attention by scientists and automobile manufactures because of their fuel consumption economy advantage, and in variable-stroke engines the pumping and frictional losses are reduced, since a short stroke is used for low engine load and longer strokes are used for high engine loads. Siegla (1978) and Siewert (1978) reported a fuel economy approaching 20% for variable-stroke engine over fixed-stroke engines. The concept of VCR can be more suitably used with the turbocharged diesel engines because of two reasons: firstly, the VCR concept is beneficial only at part load and the part load efficiency of the diesel engine is higher than that of the gasoline engine. Secondly, the diesel engine has better multi-fuel capability.

It can be obtained by altering either the clearance volume or both the clearance volume and the swept volume, some effects of lower compression ratio are the temperature of the combustion chamber decreases, the charging efficiency increases, there is a light increase in the exhaust temperature and the ignition lag increases and the maximum pressure decreases. The overall results of using VCR principle is lower thermal and structural loads and a very high specific output. On the other hand, the piston and connecting rod are chosen to show the stresses on them because they may be considered as heart of an engine. Those two parts are the most stressed components of an entire vehicle. As being the major moving parts in the power -transmitting assembly, the piston and connecting rod must be so designed that it can withstand the extreme heat and pressure of combustion. Pistons and connecting rods must also be light enough to keep inertial loads on related parts to a minimum (Jain and Vaishnav (2013)).

II. EXPERIMENTAL SETUP

This study was conducted using a 4-stroke, 4-cylinder, direct injection, water-cooled compression ignition engine. The engine has swept volume of 1500cc. Some of the engine data is shown in Table 1.

Type	Tempest, Automotive 30 test bed
Diameter (mm)	73
Stroke Length (mm)	89
Compression Ratio	21.5
Injector type	Single point, direct injection system BH-3068
Type of Injection	Direct injection system
Connecting Rod Length (mm)	165

Table 1: Engine Specifications.

As shown in Figure 1, the engine is coupled to an electric dynamometer to measure the brake torque. The electric panel is equipped with an electronic display showing the engine water inlet and outlet temperatures, coolant temperature, exhaust temperature downstream of the manifold, and oil temperature. It also displays the engine speed, load current and voltage and pressure drop across the orifice placed at the inlet manifold. Similar orifice is fitted to the cooling system to measure the coolant flow rate. The inlet manifold is connected to an air box with diaphragm at one end (near the engine side) and an orifice at its inlet. The box is also connected to an inclined manometer to measure the pressure drop (and hence air flow rate) into the engine. The other end of the box is fitted with flexible diaphragm for damping purpose of the air pulsation. The water outlet of the engine is also fitted with an orifice and manometer the test was carried out using biodiesel, which has been produced as discussed earlier.

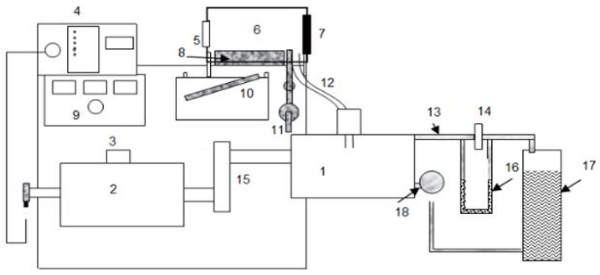


Figure 1: Engine setup.

The engine brake torque (and subsequently brake power and mean effective pressure), air-fuel ratio, and other parameters were measured at different engine speeds. These were later used in the modelling stage.

III. ENGINE SIMULATION

Engine simulation is carried out using a full cycle thermodynamic engine simulation software designed for simulating and optimizing working processes of two- and four-stroke internal combustion engines with all types of boosting. It can be used for modelling diesel engines, and engines fuelled by bio-fuels. The model was verified for both diesel and biodiesel fuel. Figures 2 and 3 show the verification of the simulation software against experimental data.

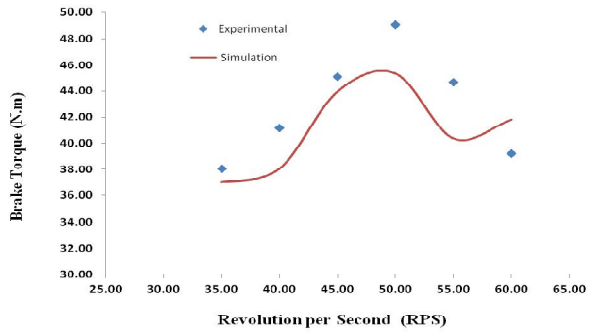


Figure 2: Brake torque VS Revolution per second for biodiesel

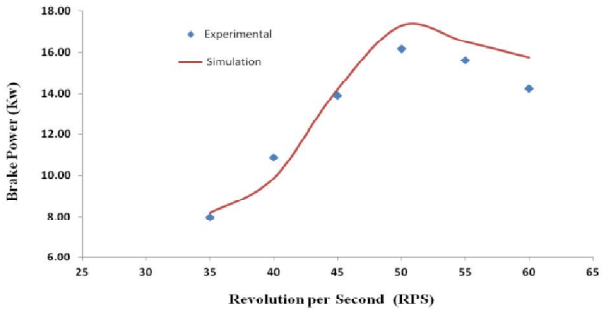


Figure 3: Brake power VS Revolution per second for biodiesel

IV. FEA SIMULATION

The CAD model (Piston, connecting rod, cap, wrist pin and crank pin) has been imported to the FEA software as shown in figure 4 (the auto-meshed model is also shown). Material properties of the model are shown in table 2.

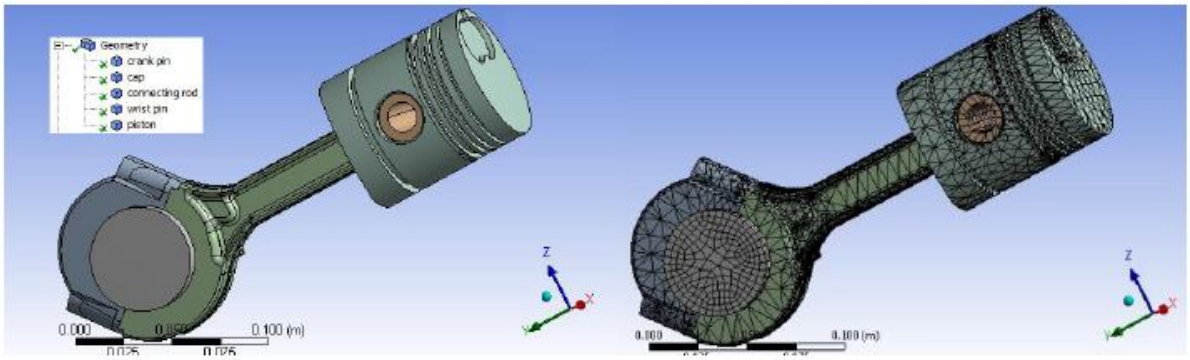


Figure 4: CAD model

Two strokes makes a full combustion cycle, first stoke is induction, the second is compression, the third is power and the fourth is exhaust, this will happen when the crank shaft rotates 720 degrees, since it is impossible to apply the simulation of the 720 degrees , 8 main degrees of the crank shaft had been consider, two degrees of the maximum pressure that had been induced in the combustion cycle for diesel and biodiesel, two degrees of the maximum temperature that had been induced in the combustion cycle for diesel and biodiesel, two degrees of the maximum heat release rate that had been induced in the combustion cycle for diesel and biodiesel, and the last two degrees were before and after injection/ignition timing that is actually happing inside the engine, which is 30 degree before TDC (330°) and 30 degree after TDC (390°), those eight points are the most effective point to simulate the stresses on the engine parts, the simulation process had been done with engine running at 1800 RPM because engine will be in the maximum load at this speed.

Part	Material	Young's modulus (GPa)	Passion's ratio	Coefficient of thermal expansion (K^-1)	Tensile yield strength (GPa)	Thermal conductivity (Wm^-1K^-1)
Piston	Aluminum Alloy	71	0.33	2.3*10^-5	0.28	144
Connecting Rod	Aluminum Alloy	71	0.33	2.3*10^-5	0.28	144
Wrist Pin	Steel	200	0.3	1.2*10^-5	0.25	60.5
Cap	Aluminum Alloy	71	0.33	2.3*10^-5	0.28	144
Crank Pin	Steel	200	0.3	1.2*10^-5	0.25	60.5

Table 1: Material properties of the piston-connecting rod model

The time for each degree of the crankshaft is calculated as follow:
1800 revolutions will be done in 60s
1 revolution =360° = 60s / 1800 revolutions = 0.03334 s
1° = 0.03334s / 360° = 0.00009259259s
From the engine simulation software, values of pressure, temperature and heat transfer factor inside the cylinder of each fuel with each compression ratio are obtained (figures 5-7)

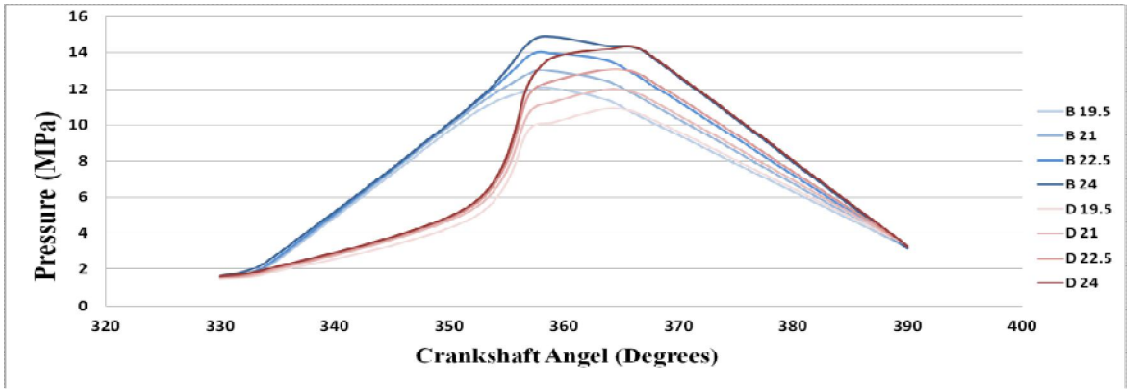


Figure 5: Pressure VS Crankshaft angel

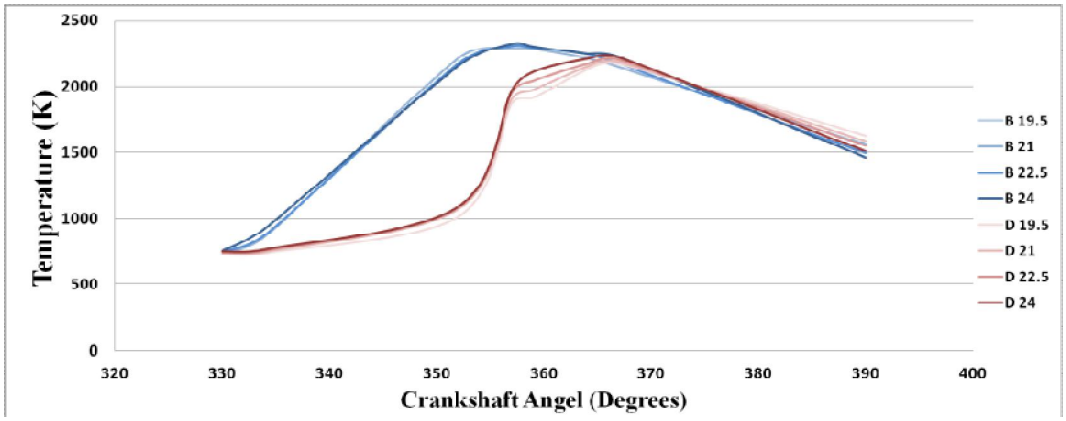


Figure 6: Temperature VS Crankshaft angel

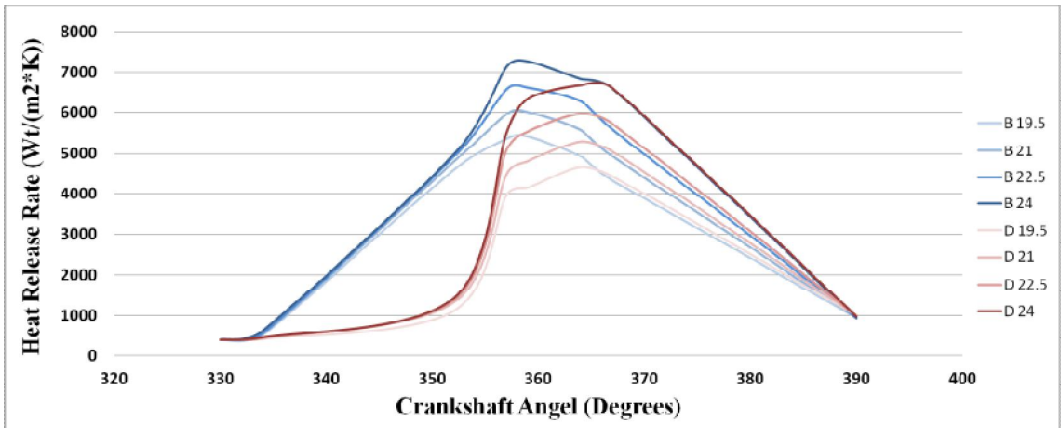
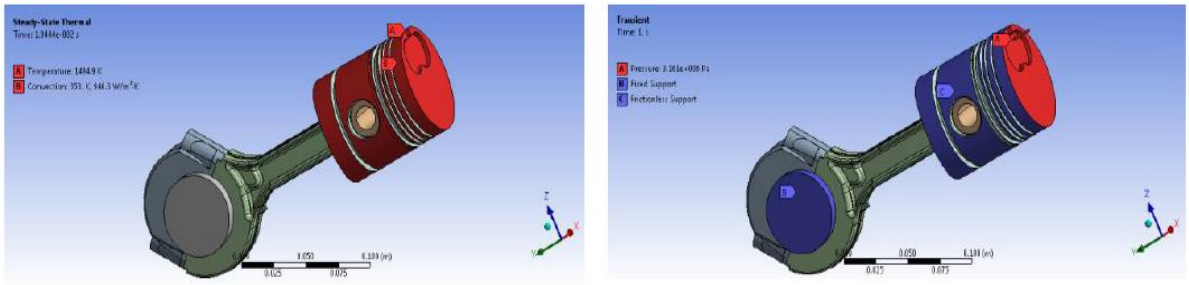


Figure 7: Heat release rate VS Crankshaft angel

Figure 8 shows the heat transfer coefficients for the model, as observed from the figure, the temperature is located and concentrated on the top of the piston and the convection is on the side.In figure 9 the structural boundary conditions that were used to simulate the piston behaviour accurately are shown. Apart from the fixed support at the crankshaft, a frictionless support was declared on the circumference of the piston to simulate the movement within the cylinder. Further, the connection between the piston and wrist pin and the wrist pin and connecting rod and connecting rod and crankshaft and the cap and crankshaft were changed from the default "bonded" to "no separation" to permit relative translational and rotary motions respectively.



V. RESULTS

Distribution of the body temperature of the whole model is shown in figures10 and 11. This temperature distribution has been imported to the structural analysis to get the results of the equivalent stress (figure 12-14).

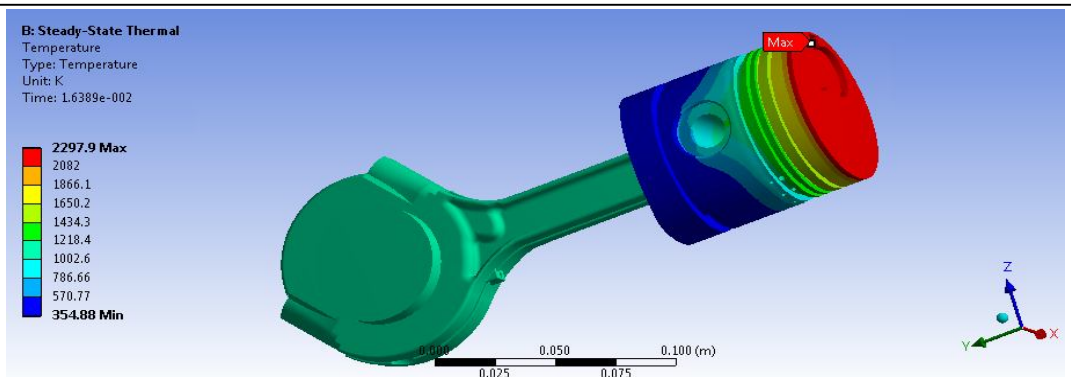


Figure 8: Temperature distribution of the whole model

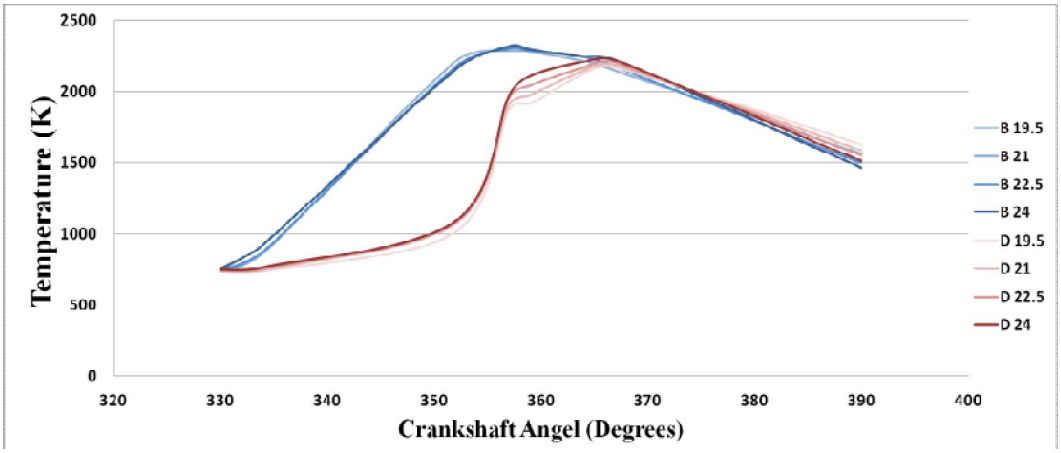


Figure 9: Temperature distribution for biodiesel and diesel for all CRs Vs crankshaft angel

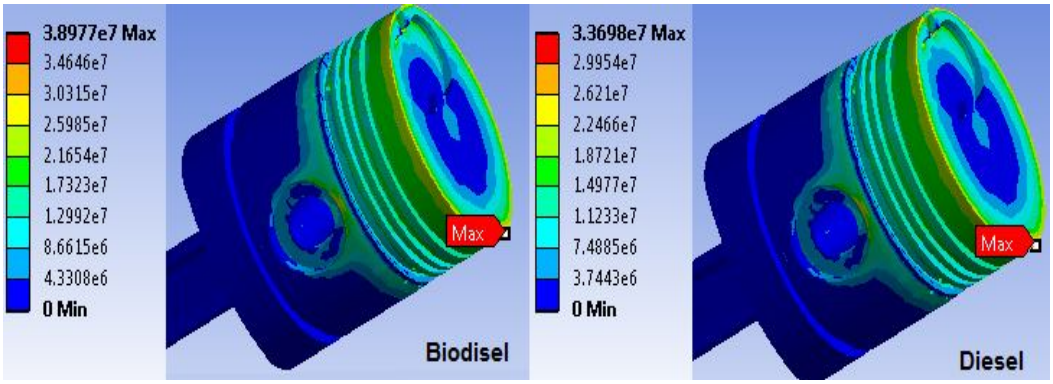


Figure 10: Equivalent stress comparison between biodiesel and diesel

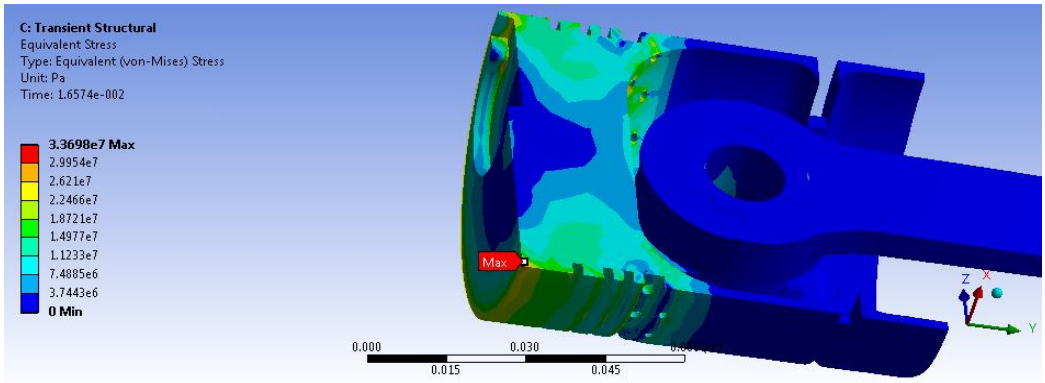


Figure 11: **Equivalent stress for diesel in a sectional view**

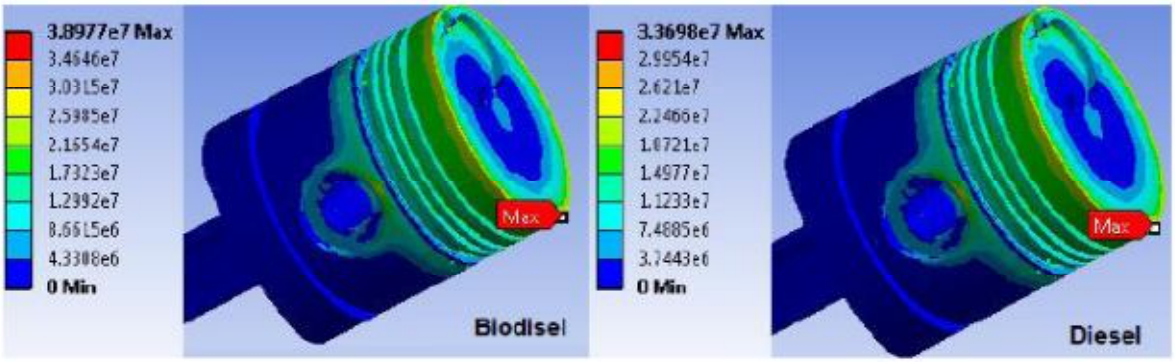


Figure 12: Equivalent stress for biodiesel and diesel for all CRs Vs crankshaft angel

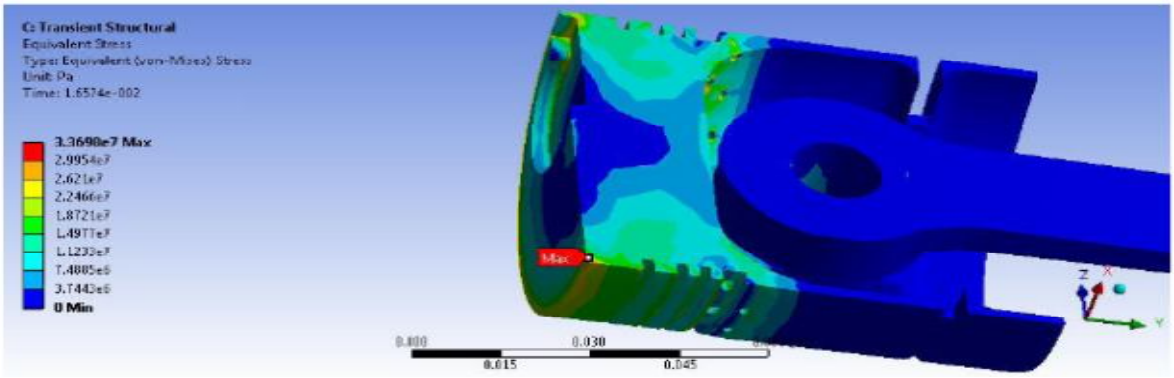


Figure 13: Equivalent stress for diesel in a sectional view

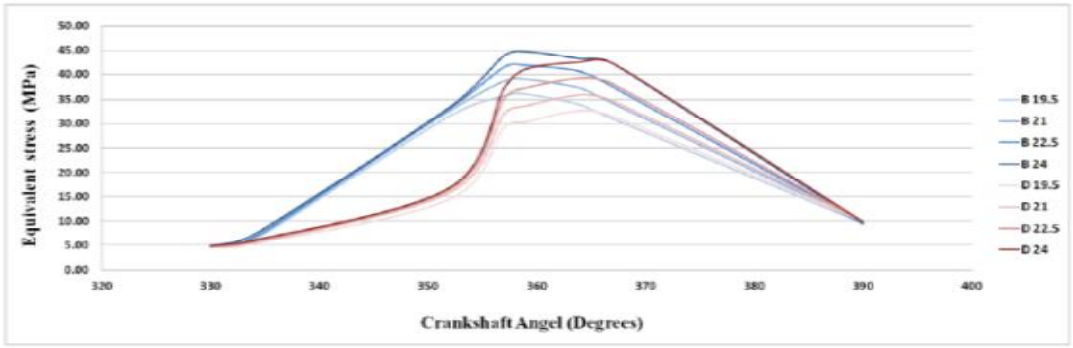


Figure 14: Equivalent stress for biodiesel and diesel for all CRs Vs crankshaft angel

As expected maximum temperature occurred on the top surface of the piston with a value of 2297.9K (357 degrees), and gradually decreasing all the way to the cap reaching a minimum value of 354.88KFigure 15 displays the temperature distribution on the piston showing the variation on temperature along it, this temperature profile conforms results obtained by other researches; biodiesel resulted in higher temperatures when compared to diesel for same CR.

The highest temperature values for both fuels occurred between 350-370 degrees of crankshaft angel. By seeing the four CR curves of biodiesel; the highest temperature value is for CR 24:1 with 2323.7K at 357°, and the lowest value at the same crankshaft angel is for CR 19.5:1 with 1871.6K, which means by reducing the CR from 24:1 to 19.5:1 we get about 20% reduced temperature at same the same crankshaft angel.

For diesel CR curves, the highest temperature value is for CR 24:1 with 2220K at 367°, and the lowest value at the same crankshaft angel is for CR 19.5:1 with 2145.7K, which means by reducing the CR from 24:1 to 19.5:1 we get about 3.5% reduced temperature at same the same crankshaft angel.These results indicates that reducing the CR in biodiesel is way more better than reducing it in diesel since the high temperatures effect badly on the stresses of the engine parts. Furthermore, biodiesel gets to the maximum temperature before the piston reach

TDC with 3° counter to diesel. Biodiesel fuel has shorter ignition delays and higher overall cylinder temperatures than diesel fuel.

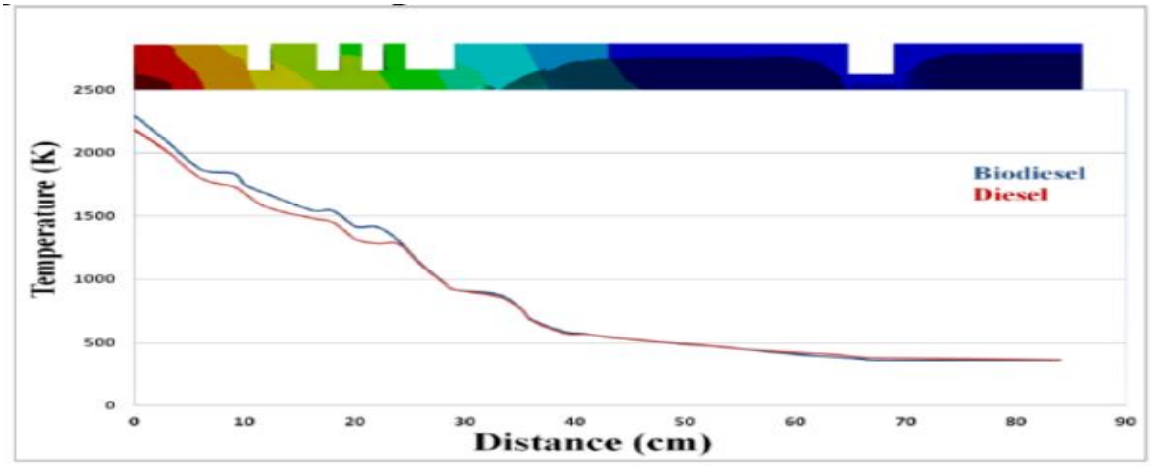


Figure 15: Temperature distribution on the piston

An Investigation on the equivalent stress in a transient structural analysis showed that the maximum equivalent stress was at the tip of the piston surface for diesel and biodiesel. A gradual decrease in the stress along the connecting rod axis was observed. This particularly an important finding as it shows that the modification of the geometry of the piston cylinder arrangement is not necessary since the critical point of stress is on the piston head with relatively reasonable value. It is notable to mention that this point of maximum equivalent stress is located opposite on the bowl of the piston head for both fuels.

The relationship between the crankshaft angel and the equivalent stress for different compression ratios was illustrated, the first band of curves (blue) were for the biodiesel, while the second band (red) were for diesel, results notably showed two completely different behaviours of the evolution of the equivalent stress with crankshaft angle. When diesel is used, gradual increase of the equivalent stress with the rotation of the crankshaft was observed compared to a sharp increase of those stresses when biodiesel is used. Furthermore, those stresses peaked at a crankshaft angle of 359 for the highest compression ratio when biodiesel was used, compared to a crankshaft angle of 364 for the highest compression ratio when using diesel.

It was found that the highest equivalent stress occurred for biodiesel 24:1 CR with a value of 44.67 MPa, while in diesel 24:1 CR the highest value was 42.53 MPa, 2.14 MPa is the difference between biodiesel and diesel for 24:1 CR.

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