Investigating the thermal characteristic of copper alloys valve seat towards engine performance enhancement of MODENAS CT115 through steady-state analysis

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Abstract. MODENAS CT115 engine is a single overhead camshaft (SOHC) engine, with a rated power of 8.8 horsepower at 9000 rpm. One of the main concerns of engine research is the overheating of engines. Overheating can affects the performance of an engine by leading to a loss of strength and thermal strain. To prevent failure, thermal analysis is used to determine the flow of heat with precision to optimise temperature distribution. The investigation is done using ANSYS Thermal simulation on the CAD model of the engine cylinder head, intake and exhaust valve, and intake and exhaust valve seat insert. The comparison to the existing valve seat insert is made using three different valve seat insert materials: Beryllium-copper C17200, Bronze-copper C61300, and Brass C36000. The research results proved that Brass C36000 provides the best thermal reduction and heat transfer increment compared to the existing valve seat insert material.

1. Introduction

Presently, development towards more energy-efficient motorcycles is a primary concern in the automotive world. The automotive industry is a highly competitive industry, where innovative design and technology play a significant role in the market share. Following National Automotive Policy (NAP) 2020, which is designed to make Malaysia a regional leader in automotive, engineering, and technology, the requirement of a motorcycle with better performance is now more crucial than ever. The launch of MODENAS CT115 in the year 2015 comes out with a four-stroke, single overhead cam.
The engine offers good performance in automotive technology and several rooms for potential improvement with a reported power of 8.8 horsepower at 9000 RPM.

Overhead engines such as this have two valves per cylinder, a part of the valve train system consisting of spring, rocker arm, cam, and valve seat inserts. To limit the flow of air into the combustion chamber is the function of the intake valve. Moreover, the exhaust valve controls the remains of the combustion gases moving out from the combustion chamber. The strong relation between the operating speed with the characteristic of heat transfer in the engine is a good platform for improvement in the engine of MODENAS CT115.

1.1. Problem statement
MODENAS CT115 engine can run at a maximum of 9000 revolutions per minute (RPM). In order to increase engine performance, the operating speed needs to increase as well. However, this will increase the exhaust gas temperature since more fuel will burn, increasing the heat in the combustion chamber. Exhaust valve runs hotter than intake valve because they receive a small amount of air for cooling purposes, receive impact from high-temperature combustion gases, and are more likely to burn and wear. Loss of engine performance is linked to the high wear that causes the valve train system to no longer seal the combustion chamber. The valve and valve seat in a spark-ignition engine will increase in temperature due to the exhaust port's hot gases. High temperatures caused by inadequate heat transfer could seriously damage the combustion chamber and the engine itself. This condition would cause a loss of performance of the engine [1]. Therefore, valve seat insert material with the best mechanical and thermal properties must be defined to increase the heat transfer rate between the valve seat insert to the valve and engine cylinder head. So this study is to determine the best valve seat insert materials out of the suggested materials compared to the existing valve seat insert.

2. Literature review
A four-stroke IC engine requires four strokes of its piston, which is done by crankshaft revolutions. The four strokes of the four-stroke spark-ignition engine refer to the moving strokes of the piston. SI engines are designed to mix fuel in the early stages, in the compression stroke. Inside the internal combustion engine, valves are subjected to different loads and temperatures [2]. The temperature difference between the intake valve and the exhaust valve is because of the difference in their surrounding or boundary conditions [3]. Differing from the intake valve, the exhaust valve is exposed to the complex thermo-mechanical load. M Cerdoun et al. [4] proposes the way to determine the consequences of the valve ambient is to use the smaller division of the valve. The coefficient heat transfer (HTC) and the adiabatic wall temperature (AWT) can be devised during a cycle of an engine from these smaller divisions. M Motahari-Nezhad et al. [5] have developed a way of investigating the heat transfer between the valve and VSI using Thermal Contact Conductance (TCC). Since the valve transfers the heat through contact to the valve seat, the study gives good relation between the heat transfers through conduction. Many factors lead to the TCC [6]. This includes the properties of the contacting components and various outside factors such as the dimensions of components that are in contact, non-contacting fraction of the surface, the materials conductivity of heat, the yield strength of the contacting components and modulus of elasticity, pressure of contact, the pressure of air, heat flux and coefficient of thermal expandability. The methodology of TCC is done by measuring the temperature gained by the exhaust valve and valve seat from an experiment. The value of TCC is calculated by using the inverse method. A finite element method study by F J Cavalieri et al. [7] stated that valves are subjected to demanding working conditions and had to take in the impact of valve seat inserts at the closing instance. An experiment of wear mechanism by P Forsberg et al. [8] in 2010 uses three combinations of valve seat inserts (VSI) and exhaust valve. The data for the thermal contact conductance test needs to be taken from actual experimental results. The experimental test method is done by considering two periodically touching rods as valve and its seat.
Previous studies had only focused on the effect of heat transfer from the combustion chamber towards the valves. Therefore, there is a gap in the study of the heat transfer of valve seat inserts inside the combustion chamber. More attention is given to the mechanical properties and chemical composition of the valve and valve seat inserts (VSI) instead of the thermal properties of the seat itself.

3. Methodology
In order to analyse the temperature and heat flux moving from the combustion chamber through the heat valve, valve seat inserts, and cylinder head, a model of the components, is created using SOLIDWORKS software. The CAD file type is then converted into a STEP file and imported into ANSYS software. Mesh is generated from the model considering the mesh element size based on the device processing limitations. Meshing was applied to divide the geometry into many elements as control volumes for numerical computation. ANSYS steady-state and transient thermal simulation is used in the current study in order to determine the overall temperature and heat flux on the engine cylinder head. The boundary conditions used in the current study are calculated using Ricardo WAVE software and validated with past studies by Cerdoun et al. [1], [3]. The model of intake and exhaust valves is divided into six different subsections according to Cerdoun et al. model before being assembled into single valves. The whole model of the cylinder head is set to element size 0.002m except the gasket surface. Both of the valves and the VSIs, and the gasket surface element size are set to 0.001m which is the smallest possible element for the current model. Figure 1 below shows the engine cylinder head model with tetrahedron meshing.

![Engine cylinder head with tetrahedron meshing method and 0.002m element size](image)

3.1. Properties of material
Table 1 gives the specifications used in defining the materials used in ANSYS steady-state and transient thermal simulation. The properties of the engine cylinder head and intake and exhaust valves are constant throughout the study. The existing valve is used as the benchmark for the new materials.

| Properties          | Beryllium copper C17200 | Bronze-copper C61300 | Brass C36000 |
|---------------------|-------------------------|-----------------------|--------------|
| Density (Kg/m³)     | 8260                    | 7950                  | 8440         |

Figure 1. Engine cylinder head with tetrahedron meshing method and 0.002m element size
3.2. Summary of boundary conditions
The boundary conditions used in the present study are solved by using Ricardo WAVE software. A specification of the MODENAS CT115 engine is inserted as input for the solver. The results of this solver would give the heat transfer coefficient (HTC) and adiabatic wall temperature (AWT) of the engine in three different regions, engine cylinder head, intake port, and exhaust port. Since the solver does not directly give the exact value of HTC and AWT for each of the seven subdivisions of the valve and valve seat, a derivation of the results is done using equations [3]. The HTC and AWT in Table 2 will be used as the boundary conditions for the ANSYS Thermal Simulation.

### Table 2. Boundary Conditions for the ANSYS Thermal Simulation.

| Parts              | Part Section            | Heat transfer coefficient (W/m²·K) | Adiabatic wall temperature (K) |
|--------------------|-------------------------|------------------------------------|---------------------------------|
| Engine cylinder head | Surface of gasket       | 150                                | 927.16                          |
|                    | Head interior wall      | 500                                | 931.20                          |
|                    | Outside cylinder surface| 500                                | 375                             |
| Exhaust valve and port | Combustion face         | 413.32                             | 1040.48                         |
|                    | Valve seat              | 1309.99                            | 678.07                          |
|                    | Valve stem (port side)  | 139.76                             | 1031.37                         |
|                    | Valve stem (guide to port) | 276.19                          | 638.20                          |
|                    | Valve stem (guide)      | 280.88                             | 370                             |
|                    | Valve stem (guide to tip) | 494.71                           | 374.89                          |
|                    | Valve stem (tip)        | 500                                | 375                             |
|                    | Exhaust port wall       | 139.76                             | 1031.37                         |
| Intake valve and port | Combustion face         | 413.32                             | 1040.48                         |
|                    | Valve seat              | 1309.99                            | 678.07                          |
|                    | Valve stem (port side)  | 68.99                              | 327.42                          |
|                    | Valve stem (guide to port) | 239.99                          | 351.36                          |
|                    | Valve stem (guide)      | 280.88                             | 370                             |
|                    | Valve stem (guide to tip) | 494.84                           | 374.89                          |
|                    | Valve stem (tip)        | 500                                | 375                             |
|                    | Intake port wall        | 68.99                              | 1003.08                         |

4. Result and discussions
The result of the transient thermal simulation done on the engine cylinder head geometry shows the temperature change over time. For the current study, a period of 200s is set as input as this will show the changes of the temperature and heat flux from the transient state into the steady-state. The analysis focuses on the area of interest, which is on the combustion face of the engine cylinder head, where the temperature is at maximum.

![Figure 2. Temperature reduction comparison for transient thermal simulation(%)](image1)

![Figure 3. Heat flux increment comparison for transient thermal simulation (%)](image2)

As shown in Figure 2, it can be assumed that there will be no significant changes in the temperature of the engine. However, changing the valve seat insert to material with different mechanical and thermal properties will cause a significant reduction of the valve seat temperature. Brass C36000
shows the highest temperature reduction on the valve seat with a 4.95% reduction compared to the existing valve seat insert material. Using Brass C36000 valve seat inserts also have the highest reduction of temperature of valve seat by 4.55% from the existing material. These results confirm that Brass C36000 provides the best temperature reduction for the exhaust and intake valve seat compared to the other materials.

Changing the valve seat insert causes a significant increase in the average heat flux of the overall engine cylinder head model, as seen in Figure 3. Using Brass C36000 as the valve seat insert material on both intake and exhaust port causes the highest heat transfer moving towards the exterior of the engine cylinder model, by 4.6% increment compared to the existing valve seat insert material. However, the Beryllium-copper C17200 valve seat insert causes the highest increment of exhaust valve seat heat flux by 6.33% compared to the existing valve seat insert material. Comparing this to the heat flux increment by Brass C36000 valve seat insert, which is 6.3%, it can be said that there is not much difference between the two. For intake VSI, Beryllium-copper C17200 gives the highest heat flux at 3.35%, while Brass C36000 gives an increment of 2.85%, and Bronze-copper C61300 gives 2.64% increment. From this result, it can be said that Brass C36000 gives the best heat flux compared to the other two materials.

5. Conclusion
The study's goal is to define a valve seat insert material with the best mechanical and thermal properties to improve the MODENAS CT115 engine in terms of temperature heat transfer performance. In the current study, the first objective is achieved by dividing the valve into several sub-sections and defining each sub-section heat transfer coefficient and adiabatic wall temperature. The boundary condition is validated with the comparison with previous researches. The second objective is achieved by analysing the heat transfer between the valve seat insert to its valve and engine cylinder head by using the benchmarked copper-based materials. Finally, the heat transfer performance of the MODENAS CT115 engine is enhanced by comparing the existing and proposed copper-based materials by using steady-state and transient thermal simulation. The temperature and heat transfer analysis using steady-state and transient thermal simulation had significantly resulted in the thermal conductivity of copper-based materials. New materials with better thermal conductivity for use as valve seats in the engine cylinder head are defined. In conclusion, current results provided by the study can give an advantage towards the development of energy-efficient motorcycles in the automotive world in terms of heat transfer enhancement for the internal combustion engine.

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