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Finite element analysis of thermo-mechanical stresses in diesel engines cylinder heads using a two-layer elastic-viscoplatic model with considering viscosity effects

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Abstract

Loading conditions and complex geometry have led the cylinder heads to become the most challenging parts of diesel engines. One of the most important durability problems in diesel engines is due to the cracks valves bridge area. The purpose of this study is a thermo-mechanical analysis of cylinder heads of diesel engines using a two-layer elastic-viscoplatic model. In this article, mechanical properties of A356.0 alloy, obtained by tensile tests at 25 and 200°C. The results of the thermo-mechanical analysis indicated that the maximum temperature and stress occurred in the valves bridge. The results of the finite element analysis of cylinder heads correspond with the simulation results, carried out by researchers. Viscous strain was significant and its amount is not negligible.

Keywords: finite element analysis, cylinder heads, valves bridge and tensile tests

Introduction

Cylinder heads are the important parts of the internal combustion engines which are under thermo-mechanical stresses for the sake of their working type (Azadi et al., 2012; Gocmez and Pishinger, 2011; Li et al., 2013 ; Metzeger et al., 2014; Su et al., 2002; Thalmair et al., 2006; Trampert et al., 2008; Zahedi and Azadi, 2012; Xuyang et al., 2013). Therefore, selection of materials is of paramount importance since they must have sufficient mechanical strength at high temperatures to be able to withstand cyclic stresses caused by heat and pressure (Gocmez and Pishinger, 2011; Zahedi and Azadi, 2012; Takahashi et al., 2010).

High output capacity, low fuel consumption, low emission and reducing the cost of maintenance are among the restrictions making the design of cylinder heads a complicated task (Mirsalim et al., 2009; Li et al., 2013). Thus, detailed analysis and design are essential. Escalation in environmental concerns and fuel costs underlines the need for research on more efficient engines with less energy dissipation and emission (Azadi et al., 2012; Mirsalim et al., 2009). One way to decrease the fuel costs is to reduce the weight of vehicles. Hence, lighter alloys must be used in pursuit of this goal (Azadi et al., 2012; Zahedi and Azadi, 2012). Recently, the use of aluminum alloys has increased for economic reasons and for improvement of engine power by weight reduction. Aluminum-Silicon is a casting alloy which has extensive use in the automotive industry, especially in cylinder heads of diesel engines. These materials have been replaced by a variety of cast iron which were previously used in the manufacture of cylinder heads (Azadi et al., 2012). Thermal deformation is the greatest challenge faced by the aluminum cylinder heads (Takahash et al., 2002).

Cylinder heads are exposed to thermal and mechanical loads. The temperature difference, which is the result of turning the engine on and off, begets thermo-mechanical fatigue (TMF) loads on the cylinder heads (Azadi et al., 2012; Li et al., 2013; Mirsalim et al., 2009; Farrahi et al., 2014; Thomas et al., 2002; Thomas et al., 2004) and consequently reduces their lifetime, especially in thinner regions (Remy and Petit, 2001). The crucial regions include the valves bridge and areas near spark plugs and injectors (Gocmez and Pishinger, 2011; Shojaefard et al., 2006; Ziehler et al., 2005). Cylinder heads endure out-of-phase TMF. Namely, the maximum stress occurs at the minimum temperature and the minimum stress occurs at the maximum temperature. When the engine shuts off and the temperature is low, the tensile stresses arising from assembly loads will be applied to cylinder heads. As the engine starts and temperature increases the compressive stresses produced by thermal loading (σ_{th}) and combustion pressure (σ_p) will be applied to them (Azadi et al., 2012; Li et al., 2013). This type of loading is displayed in Figure 1. As the figure reveals the changes in stress caused by thermal load is very high. The fluctuating stresses come out of the engine which is been heated and cooled (Mirsalim et al., 2009; Challen and Baranescu, 1999; Chamani et al., 2009).

Plastic deformation is observed in structures like cylinder heads which bear high temperature fluctuations and assembly loads. Classical models are used to obtain steady response of these structures. This approach is very expensive. Because many loading cycles are required to obtain a steady response. Cyclic analysis is used in order to avoid the cost of transient analysis (Zahedi and Azadi, 2012).

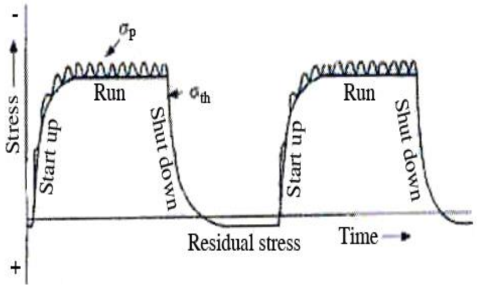

Fig.1 The cyclic loading of cylinder head (Challen and Baranescu, 1999)

Numerous papers have been presented on analysis of stress and fatigue in cylinder heads. Koch et al. measured experimentally strain of cylinder heads and compared with simulated results using a nonlinear isotropic/kinematic hardening model. A slight difference between the experimental and simulated strain was observed from 55°C to 120° C. The simulated strain by increasing temperature from 110°C to 210°C was estimated more than the experimental strain due to plastic deformation of the cylinder heads (Koch et al., 1999).

Takahashi et al. examined creep in aluminum cylinder heads. There is concordance between experimental and calculated strain. Creep strain increases as stress grows. Creep strain at 250°C significantly was higher than creep strain at 100°C and 175°C (Takahashi et al., 2002).

TMF of cylinder heads was studied by Thomas et al. using the energy model and elasto-viscoplastic law. Their research proved a good agreement between experimental and simulated results of the fatigue life of the cylinder heads and the location of crack initiation (Thomas et al., 2002; Thomas et al., 2004).

Thermo-mechanical analysis of cylinder heads and cylinders of AFV diesel engines was conducted by Venkateswaran et al. Their research demonstrates that the cylinder heads and engine blocks can tolerate more stress caused by pressure and thermal loads increase and the next generation of engines do not need further alteration (Venkateswaran et al., 2011).

Su et al. predicted fatigue life of cylinder heads by finite element simulation via the model of damage total (Sehitoglu damage model) and compared with experimental results. Their research revealed that the difference between experimental and simulated results is less than 30% (Su et al., 2002).

Zieher et al. simulated the complete process of lifetime. They used energy model to predict the fatigue life of cast iron cylinder heads. Their research shows the simulated results of the number of cycles of crack initiation and the location of crack initiation are in accord with experimental results. The minimum lifetime was observed in the valves bridge (Ziehler et al., 2005).

The analysis of high/low cycle fatigue of cylinder heads was performed by Ghasemi using the thermo-mechanical analysis results. His study verified that the cracks observed in the experimental test of low-cycle of cylinder heads acknowledged the simulated results of low-cycle fatigue. The simulated results of low-cycle fatigue of cylinder heads after modification of cooling systems indicates that high levels of damage parameters do not observe (Ghasemi, 2012).

Shoja'efard et al. experimentally measured the stress in cylinder heads and compared with simulated results. Their research confirmed the concordance between the experimental and simulated results at low temperature. The simulated stress at temperatures exceeding 200°C was estimated to be greater than the experimental stress by reason of the inelastic material deformation (Shoja'efard et al., 2006).

Prediction of the fatigue life of cylinder heads of two-stroke linear engines was done by Rahman et al. using finite element analysis (FEA) and stress-life approach. Their research refuted the possibility of failure in all spots. Compressive mean stress increases the fatigue life and tensile mean stress lessens the fatigue life (Rahman et al., 2008).

Gocmez and Pischinger investigated the sophisticated interaction effects of thermal and mechanical loads, geometry of cylinder heads and TMF behavior of cylinder heads material. They optimized the valves bridge based on the ratio of mechanical to thermal strain. Their research indicates that the vertical temperature gradients are mainly determined by the thickness of the valves bridge which plays a role in distribution of temperature. Geometric dimensions of the valves bridge and thermal conductivity were the most outstanding parameters in the thermo-mechanical analysis of cylinder heads (Gocmez and Pishinger, 2011).

Thalmair et al. established the TMF/computer aided engineering (CAE) process for the fatigue assessment of cylinder heads. Their research proved an acceptable agreement between experimental and simulated results of the fatigue life of the cylinder heads. They predicted the locations of fatigue cracks in cylinder heads accurately (Thalmair et al., 2006).

Mirslim et al. calculated low cycle fatigue life by simulation of finite element of cylinder heads based on various criteria of strain based. Their experiments show by cutting the valves bridge we can increase the fatigue life of cylinder heads (Mirslim et al., 2009).

Tramprt et al. studied the effects of thermo-mechanical loads on cylinder heads. Their research indicated concordance between experimental and simulated results of the fatigue life of cylinder heads. Crucial locations in the analysis of fatigue were the same locations of crack initiation in the experimental conditions. There was conformity between the number of cycles of calculated failure and the experimental results of macroscopic observation of cracks (Tramprt et al., 2008).

Zahedi and Azadi compared the stress and low-cycle fatigue life of aluminum and magnesium cylinder heads of diesel engines. Their research showed that the strain in magnesium cylinder heads was more in comparison with the aluminum ones, while the magnesium cylinder heads had less stress. The fatigue life of the both cylinder heads was almost identical (Zahedi and Azadi, 2012).

Azadi et al. analyzed cracked cylinder heads of gasoline engines. Examining materials and doing finite element analysis of cracked cylinder heads stress, they determined the cause of cracks and provided some solutions. Their research revealed that the main reason for cracks initiation in cylinder heads is high stress and plastic strain caused by assembly loads of cylinder heads bolts (Azadi et al., 2012).

TMF analysis of gray cast iron cylinder heads was conducted by Lee et al. An acceptable agreement between experimental and simulated results of TMF life was proved. Improving and optimizing the structure of cylinder heads doubled their fatigue life (Li et al., 2013).

Xuyang et al. predicted TMF life of diesel engines cylinder heads. Their research revealed that the discrepancy between experimental and simulated results is 3%. The energy criterion accurately predicted fatigue life in the valves bridge compared with thermal shock test (Xuyang et al., 2013).

Metzger et al. predicted the lifetime of cast iron cylinder heads under thermo-mechanical loads and high-cycle fatigue. According to their study the experimental and simulated results of temperature match. The mechanical analysis correctly anticipated the position and direction of cracks in the valves bridge. Comparing with experimental results, the anticipation of fatigue life was rather conservative (Metzeger et al., 2014).

Aluminum cylinder heads must be adequately robust to tolerate gas pressure, assembly loads and high temperature resulting from ignition to avoid cracking the valves bridge (Takahashi et al., 2010). Thermo-mechanical loading cylinder heads can only be controlled through modern cooling systems or protective coatings such as thermal barrier coating (TBC) that reduces heat stress and thereby reduces the temperature gradient (Bialas, 2008).

Azadi and colleagues studied the impact of TBC on cylinder heads. The results of their research demonstrated the TBC reduced the temperature gradient and consequently the thermal stress reduced. Ergo, fatigue life of cylinder heads augmented (Azadi et al., 2013; Moridi et al., 2011; Moridi et al., 2014).

According to the introduction, due to the lack of information on the behavior of hardening, softening and viscosity of materials the analysis of cylinder heads is mostly based on simple models of material behavior like elastic-plastic and the effects of viscosity and creep of cylinder heads are less taken into consideration. Aluminum alloy has creep behavior at about 300°C and viscosity should also be taken into accounted (Su et al., 2002; Thomas et al., 2002; Thomas et al., 2004; Koch et al., 1999). The main objective of this study was to simulate the thermo-mechanical behavior of cylinder heads based on the two-layer elastic-viscoplatic model. In some analyses, it is assumed that temperature changes have no effect on the stress-strain curves and thermo-mechanical analysis of cylinder heads is non-coupled. Since changes in temperature influence on stress-strain curves, the thermo-mechanical analysis of cylinder heads in this study is coupled.

2. Experimental tensile tests

In this study the cast alloy of aluminum-silicon-magnesium has been used to simulate the thermo-mechanical behavior. The alloy is known as A356.0 or AlSi7Mg0.3 which is applied in diesel engines cylinder heads (Farrahi et al., 2014; Moridi et al., 2011; Moridi et al., 2014). The chemical composition of the A356.0 is 7.06 wt.% Si, 0.37 wt.% Mg, 0.15 wt.% Fe, 0.01 wt.% Cu, 0.02 wt.% Mn, 0.13 wt.% Ti, and Al remainder (Farrahi et al., 2014). In this article, mechanical properties of A356.0 alloy, obtained by tensile tests based on ASTM E8-E8M standard. Tensile tests were performed under a strain-controlled condition. All tests were conducted using a servo-hydraulic MTS-810 material testing machine (MTS, USA) at 25 and 200°C. The specimen geometry and its dimensions are shown in Figure 2.

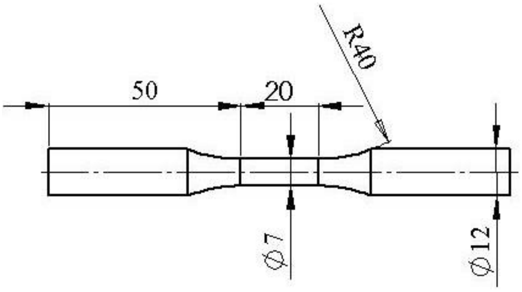

Fig.2 The tensile specimen geometry and its dimensions(in mm)

During tensile tests, the temperature was measured by an infrared pyrometer and a high temperature extensometer was used for measuring the strain. An induction system was applied for heating the specimen(Figure 3).

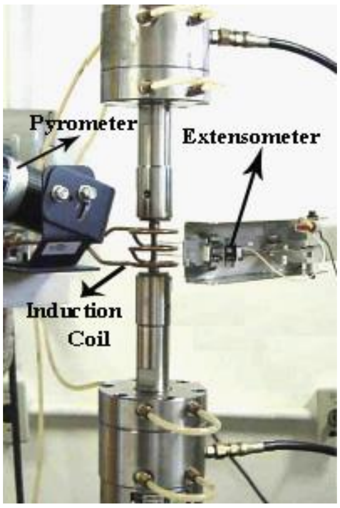

Fig.3 Material testing machine MTS 810

3. The material behavioral model

The two-layer elastic-viscoplatic model divides the elastic and viscosity effects into two elastic-viscous and elastic-plastic networks. As displayed in Figure 4, this model is presented by Kichenin (Kichenin et al., 1996). This model makes the cyclic stress-strain behavior of the material predictable with reasonable accuracy (Deshpande et al., 2010).

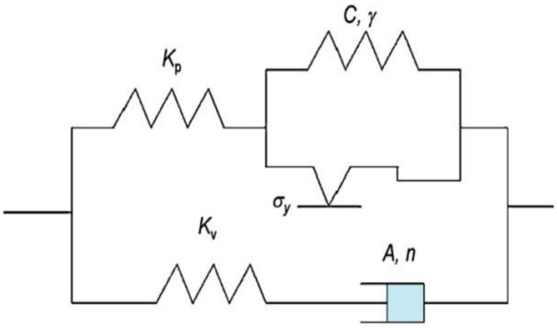

Fig.4 The two-layer elastic-viscoplatic model (Deshpande et al., 2010)

This model consists of a network of elastic-plastic parallel to a network of elastic-viscous. Plastic deformation and creep can be seen in structures such as cylinder heads of engines which are under assembly loads and temperature fluctuations. The two-layer elastic-viscoplatic model is the best to examine the response of materials such as aluminum cylinder heads which have remarkable dependent behavior on temperature and plastic at high temperatures (Metzeger et al., 2014; Farrahi et al., 2014; Zahedi and Azadi, 2012; Deshpande et al., 2010; Thalmair et al., 2006). This model is in good agreement with results of experimental and thermo-mechanical test of A356.0 alloy (Farrahi et al., 2014).

The material behavior of different Aluminum-Silicon casting alloys was described by the nonlinear kinematic/isotropic hardening model of Abaqus software (Koch et al., 1999).

In the plastic network nonlinear kinematic/isotropic hardening model is applied which predicts the behaviors such as hardening, softening, creep and mean stress relaxation and and it is a suitable model for the plastic behavior of materials (Farrahi et al., 2014; Deshpande et al., 2010).

Kinematic hardening has both linear and nonlinear isotropic/kinematic model. The first model can be used with Mises or Hill yield surface while the second one can only be used with the Mises yield surface and it is the most accurate and comprehensive model to examine some issues with cyclic loading including cylinder heads of engines. The kinematic hardening model assumes that the yield surface, proportional to the value of α, moves as back stress in yield zone but it does not deform (Lemaitre and Chaboche, 1990). Abaqus software uses ziegler linear model (Lemaitre and Chaboche, 1990) to simulate this model as following equation shows:

$$\dot{\alpha}=C\frac{1}{\sigma^0}(\sigma_{ij}-\alpha_{ij})\dot{\bar{\varepsilon}}^{PL}+\frac{1}{C}\dot{C}\alpha_{ij} \qquad (1)$$

Where C is kinematic hardening modulus, $\dot{C}$ is of exchange rate of C in temperature and $\dot{\bar{\varepsilon}}^{PL}$ is the rate of equivalent plastic strain. In this model σ^0 (the size of the yield surface) remains constant. In other words, σ^0 is always equal to σ_0 (that is yield stress in zero plastic strain) remain constant. Nonlinear isotropic/kinematic hardening model includes motion of yield surface proportional to the value of α in stress zone and also changes in the size of yield surface is proportional to the plastic strain (Lemaitre and Chaboche, 1990). This model has been extracted from Chaboche experience(Chaboche, 1986; Chaboche, 2008). In order to introduce this model a nonlinear term is added to equation (1) to indicate the size of yield surface (Lemaitre and Chaboche, 1990).

The Abaqus software uses nonlinear isotropic/kinematic hardening model as following equation shows:

$$\dot{\alpha}=C\frac{1}{\sigma^0}(\sigma_{ij}-\alpha_{ij})\dot{\bar{\varepsilon}}^{PL}-\gamma_{ij}\dot{\bar{\varepsilon}}^{PL}+\frac{1}{C}\dot{C}\alpha_{ij} \qquad (2)$$

Where C and γ are material constants. In order to introduce this model in Abaqus software the isotropic and the kinematics parts are required to be defined separately (Farrahi et al., 2014). In order to define the isotropic part the equation (3) is used in which b and $Q_\infty$are material constants (Deshpande et al., 2010).

$$\sigma^0=\sigma_0+Q_\infty(1-\exp(b\dot{\bar{\varepsilon}}^{PL}) \qquad (3)$$

The overall back stress is computed from the relation (4) (Lemaitre and Chaboche, 1990):

$$\alpha=\sum_{K=1}^{N}\alpha_K \qquad (4)$$

In equation (4) if we consider N equal to 3, the hardening variable is divided into three parts which increases the accuracy of the model (Farrahi et al., 2014).

Norton-Hoff law is used viscous network in order to consider the effect of strain rate, the equation of which is the following (Angeloni, 2011):

$$\dot{\varepsilon}_V=A(\sigma_V)^n \qquad (5)$$

Where the $\dot{\varepsilon}_V$ is viscous strain rate, A and n are material constants and σ_V is the viscous stress.

According to equation (6) the rate of the elastic modules in the two viscous and plastic networks is express by f. Where k_v and k_p are elastic modules in the elastic-viscous and elastic-plastic networks respectively (Deshpande et al., 2010).

$$f=\frac{k_v}{k_v+k_p} \tag{6}$$

4. The finite element model and material properties

Traditionally, optimization of engine components such as cylinder heads was based on building a series of physical prototypes, and performing a series of different experiments and tests. Unfortunately, this method is time consuming and building a prototype in the early stages of the design is arduous. Many samples must be constructed and tested in order to achieve the precise design. This process is costly. These problems have been resolved using finite element analysis to evaluate the effectiveness of various designs. This technique is accepted for the design and development of geometrically complex components such as cylinder heads in a shorter period and with the least cost. Cylinder heads are complex and challenging components of engines, for which the finite element analysis plays a critical role in optimization (Shojaefard et al., 2006). TMF analysis of each component needs the cyclic stress-strain distribution. Hot components of diesel engines had complex geometry and loading, and the applying analytical methods for the detection of stress-strain distribution in them is impossible. Many researchers have used finite element method to obtain stress-strain distribution in of geometrically complex components (Sun and Shang, 2010). Nowadays, simulation techniques are substitute to validation tests so as to decrease the cost and time of production (Trampert et al., 2008). Cylinder heads examined in this study are shown in Figure 5.

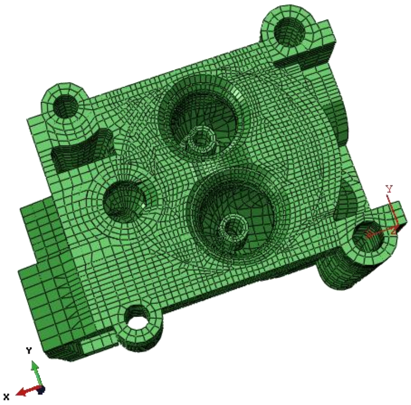

Fig.5 The meshed cylinder head (ABAQUS/CAE User' s Manual, 2010)

Cylinder heads have three valve ports, each with an embedded valve seat; two valve guides; and four bolt holes used to secure the cylinder heads to the engine blocks. Cylinder heads are made of aluminum alloy (A356.0). The two valve guides are made of steel, with a Young's modulus of 106 GPa and a Poisson's ratio of 0.35. The valve guides fit tightly into two of the cylinder heads and their behavior is presumed elastic. The three valve seats are made of steel, with a Young's modulus of 200 GPa and a Poisson's ratio of 0.3. The valve seats are press-fit into the cylinder head valve ports. This is accomplished by defining radial constraint equations (ABAQUS User' s Manual, 2010).

The model consists of 65580 nodes and approximately 80000 degrees of freedom. Cylinder heads loading was done in two phases involving thermal analysis and mechanical analysis.

The values of f, n, A and Q_∞ were extracted from the experimental results of A356.0 from source (Farrahi et al., 2014) and they were entered into the Abaqus software.

There are several methods to insert the values of C and γ into Abaqus software that one of them is entering yield stress at plastic strain using tensile test result (ABAQUS User' s Manual, 2010). The yield stress at plastic strain was extracted from tensile test result and entered into the Abaqus software.

5. Results and Discussion

5.1 Experimental tensile tests results

The stress-strain curves of A356.0 alloy at two temperatures (25 and 200°C) are shown in Figures 6 and 7.

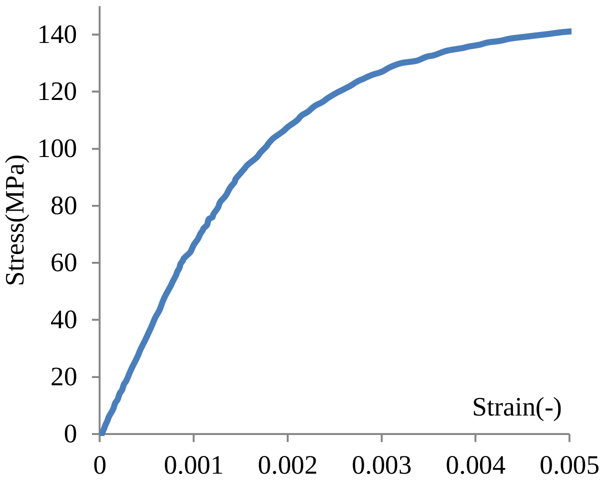

Fig.6 Stress-strain behavior in tensile test of A356.0 alloy at 25°C

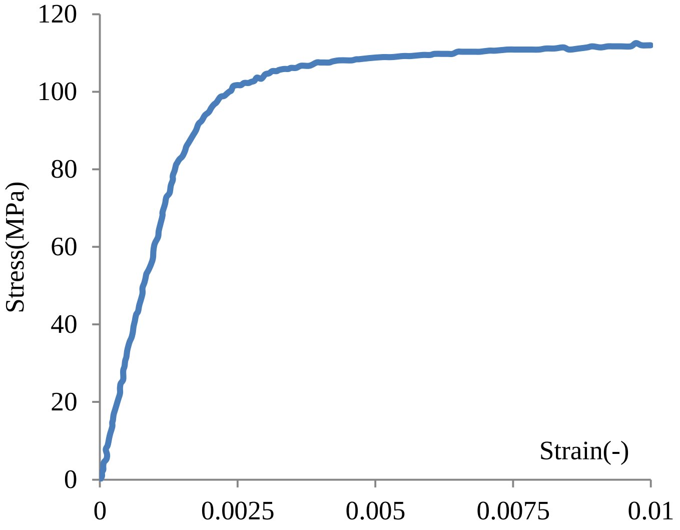

Fig.7 Stress-strain behavior in tensile test of A356.0 alloy at 200°C

5.2 Thermal Analysis

Thermal stresses in the cylinder heads are the dominant stresses, leading to low cycle fatigue in the cylinder heads. Low cycle fatigue of cylinder heads is caused by repeated start-up and shout-down cycle of the engine (Mirsalim et al., 2009; Thomas et al., 2002; Thomas et al., 2004; Ghasemi, 2012).
The main part of cylinder heads stresses is the result of the thermal loading and the rest is caused by the combustion pressure and mechanical constraints (Figure 1)(Mirsalim et al., 2009; Shojaefard et al., 2006). Therefore, thermal loading is the most important loading in the thermo-mechanical analysis of cylinder heads. Knowing the precise distribution of temperature in the cylinder heads increases the accuracy of thermal analysis(Mirsalim et al., 2009). Accurate prediction of the temperature of the

engine is very crucial and increases the precision of the FEA results (Ghasemi, 2012). As the accuracy of thermal analysis increases the accuracy of mechanical analysis and fatigue life estimation rises (Thomas et al., 2002; Thomas et al., 2004). The combustion pressure causes high cycle fatigue in cylinder heads (Azadi et al., 2012; Metzeger et al., 2014). Many researchers believe that the combustion pressure has secondary effect in the TMF of cylinder heads (Takahash et al., 2002; Thomas et al., 2002; Thomas et al., 2004). In finite element simulation the valves bridge, where the greatest thermal concentration exists, is subjected to thermal loading ranging from a minimum of 35°C to a maximum of 300°C (Zahedi and Azadi, 2012). The temperature distribution when the cylinder heads are heated to its peak value is shown in Figure 8. Thermal loading has a considerable effect on the fatigue life and the temperature field identifies critical regions (Trampert et al., 2008). Crack initiation is due to the changes in the temperature field (Thalmair et al., 2006).

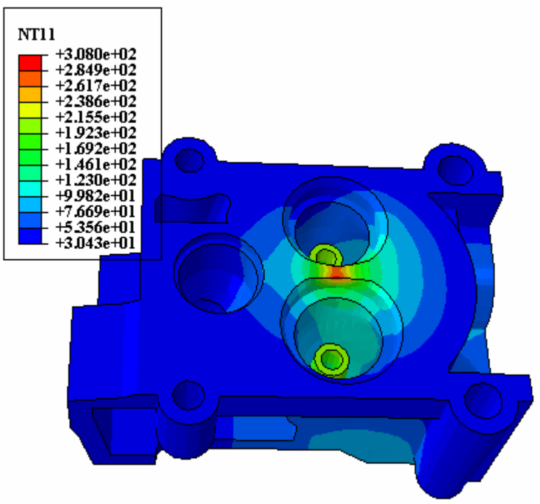

Fig.8 The temperature distribution in the cylinder head

Plastic deformation and creep are observed under such conditions. The two-layer elastic-viscoplatic model is ideally suited to examining the response of materials in these conditions (Metzeger et al., 2014; Farrahi et al., 2014; Zahedi and Azadi, 2012; Deshpande et al., 2010). The cyclic thermal loads are obtained by performing an independent thermal analysis. In this analysis three thermal cycles are applied to obtain a steady-state thermal cycle. Each thermal cycle involves two steps: heating the cylinder heads to the maximum operating temperature and cooling it to the minimum operating temperature using the *CFLUX and *FILM options. The nodal temperatures for the last two steps (one thermal cycle) are assumed to be a steady-state solution and results are stored for use in the subsequent thermal-mechanical analysis (Zahedi and Azadi, 2012). The maximum temperature occurred in the valves bridge.

The lower temperature of the flame and the gradient temperature of the parts of cylinder heads, the less thermal stress. Thus, low cycle fatigue life of the cylinder heads which is mainly affected by thermal fatigue will increase (Chamani et al., 2009).

5.3 Mechanical analysis

Mechanical analysis was carried out in two stages. In the first stage the three valve seats are press-fit into the corresponding cylinder heads valve ports. A static analysis procedure is used for this purpose. The maximum principal stress distribution is depicted in Figure 9 proving the stress in the valves bridge is tensile.

The cyclic thermal loads are applied in the second analysis step. It is assumed that the cylinder heads are securely fixed to the engine blocks through the four bolt holes, so the nodes along the base of the four bolt holes are secured in all directions during the entire simulation (Zahedi and Azadi, 2012). Von-Mises stress distribution at the end of the second stage is shown in Figure 10. The maximum stress, the same as maximum temperature, occurred in the valves bridge.

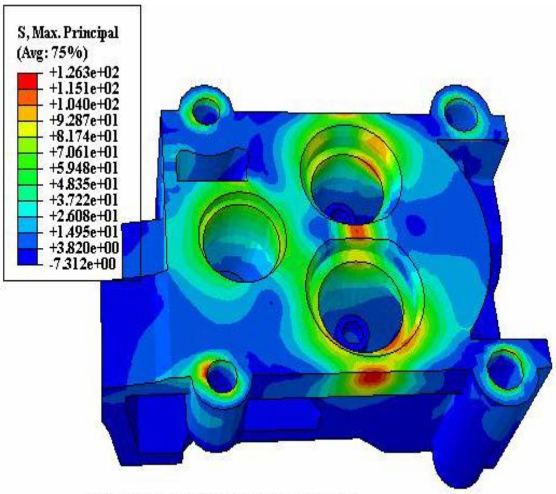

Fig.9 The maximum principal stress distribution in the first stage of mechanical loading

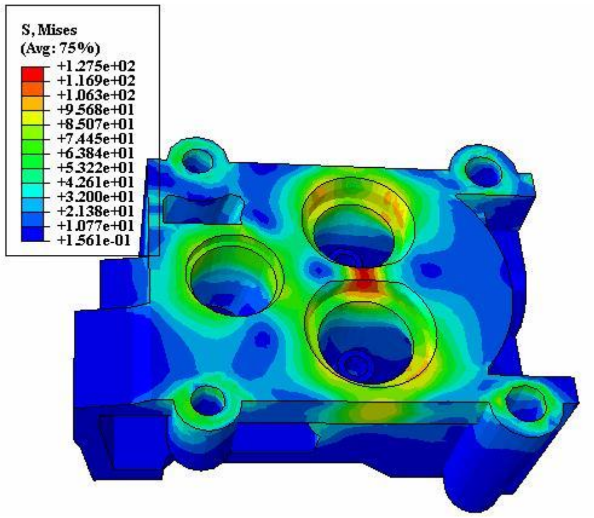

Fig.10 The Von-Mises stress distribution at the end of the second stage of mechanical loading

The results of the thermo-mechanical analysis of cylinder head carried out by researchers is shown in Figure 11 and 12.

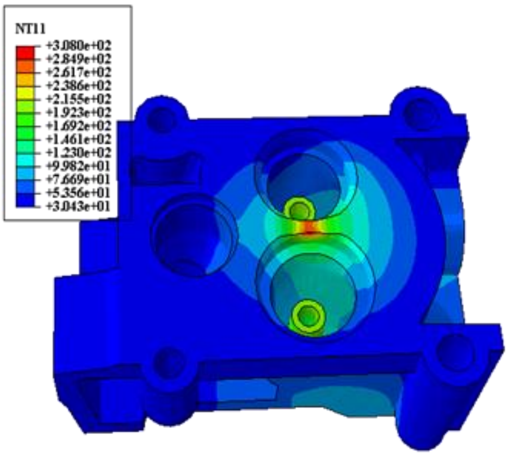

Fig.11 The temperature distribution in the cylinder head(Ashouri, 2015)

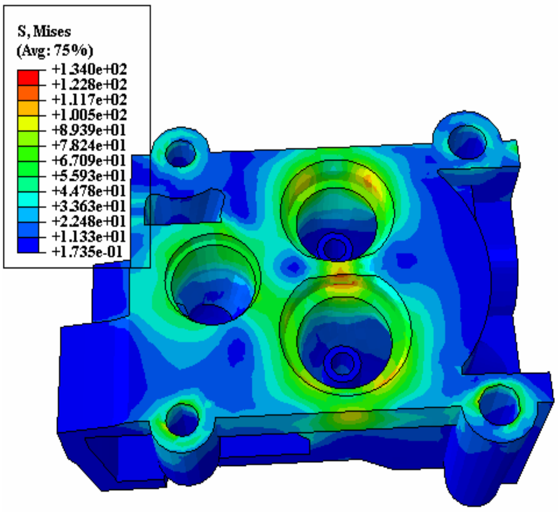

Fig.12 The Von-Mises stress distribution at the at the end of the second stage of mechanical loading(Ashouri, 2015)

The review of Figures 8 and 10 to 12 reveals there is good agreement between finite element analysis and simulation results of cylinder head, carried out by researchers. The maximum stress, the same as maximum temperature, occurred in the valves bridge. Thermal expansion of hot spots in cylinder heads are constrained by cool regions which have less thermal expansion. As a result, the compressive stress is created in the valves bridge which corresponds to the results of the source (Shojaefard et al., 2006). Based on the source (Metzeger et al., 2014), the first fatigue cracks can be seen at the hottest spot of cylinder heads (Figure 8). This region is located in the valves bridge. As stated in sources (Li et al., 2013; Koch et al., 1999) the initiation of fatigue cracks in cylinder heads occurs where stress is tensile for the sake of assembly loads and plastic strain happens because of thermo-mechanical loads. This region is also located in the valves bridge.

The valve bridge is a crucial region(Gocmez and Pishinger, 2011; Li et al., 2013; Takahashi et al., 2010; Shojaefard et al., 2006; Ziehler et al., 2005). The changes of Von-mises stress in this area are shown in Figures 13 to 15. As presented in Figures 13 to 15, the valve bridge is under high stress fluctuations. The location of cracks in cylinder heads is in the valves bridge. This region endures maximum stress due to the less thickness of material and high temperature caused by lack of proper cooling. Ergo, the cylinder heads will crack. Stress functions inversely to the thickness of the material. Namely, the thinnest locations withstand the highest stress. If the valves bridge becomes wider, it will be cooled better and consequently temperature gradient and thermal stress will reduce. Thus, fatigue life of cylinder heads increases (Gocmez and Pishinger, 2011).

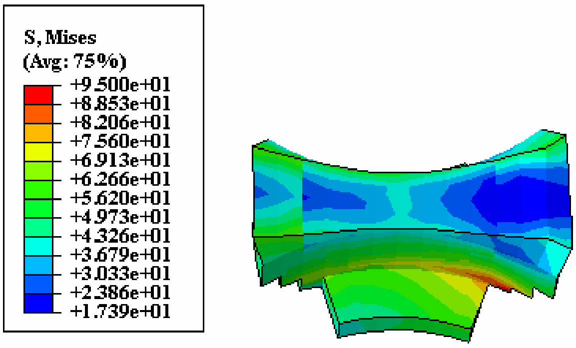

Figure. 13 The Von-Mises stress distribution in the valve bridge (in tenth second)

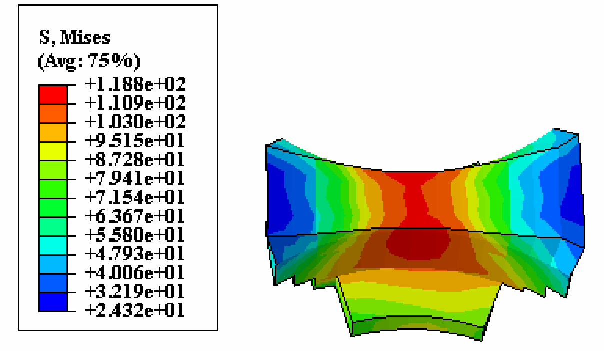

Figure. 14 The Von-Mises stress distribution in the valve bridge (in twentieh second)

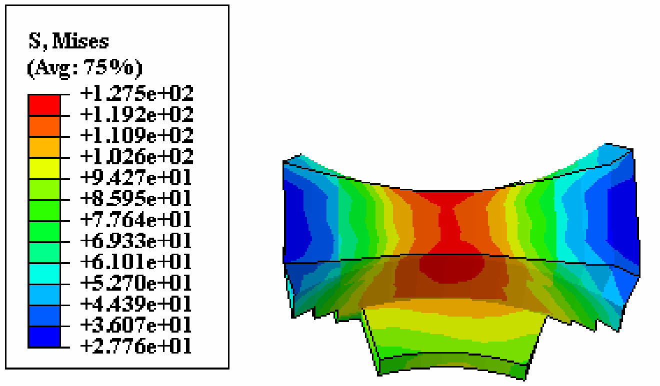

Figure. 15 The Von-Mises stress distribution in the valve bridge (in thirtieth second)

Diagrams of elastic strain and the viscous strain for point 1 of element 50152 are displayed in Figure 16. These elements are in the valves bridge. As the Figure describes viscous strain is significant and its amount is not negligible. Thus, viscous properties must be considered in the thermo-mechanical analysis of cylinder heads.

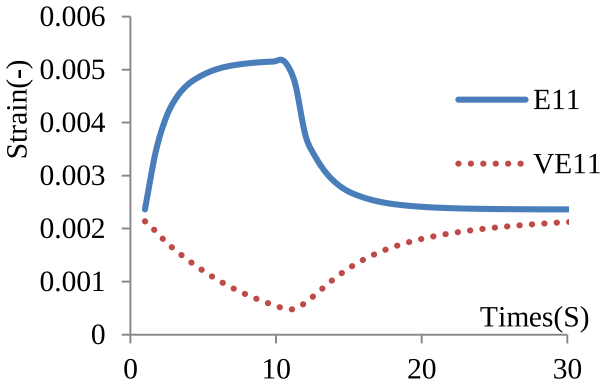

Fig.16 The elastic strain and viscous strain for point 1 of element 50152 versus time

6. Conclusion

In this study coupled thermo-mechanical analysis of diesel engines cylinder heads was studied. A two-layer elastic-viscoplatic model was used for this purpose. Mechanical properties of A356.0 alloy, obtained by tensile tests. The results of the FEA indicated that the maximum temperature and stress occurred in the valves bridge. The results of the thermo-mechanical analysis of cylinder heads correspond with the simulation tests, carried out by researchers. In order to prevent cylinder heads cracking it is recommended to modify cooling system of engines and thickness and geometry of material in crucial parts. TBC might also be used in the regions which not only boost the engine performance, but also increase the fatigue life of cylinder heads. Materials of high thermal conductivity can be used in the regions. Materials of high thermal conductivity decrease the maximum temperature in this region, leading to the increase in fatigue life of the cylinder heads. Cutting the valves bridge approaches the region to cylinder heads cooling jackets. Consequently, the temperature in the region decreases and fatigue life of the cylinder heads increases. The thermo-mechanical analysis of the cylinder heads can determine the optimum cutting to achieve the desired lifetime. Viscous strain was significant and its effect is not negligible. Thus, viscous properties must be considered in the thermo-mechanical analysis of cylinder heads.

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