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# Mechanical and Thermo Mechanical Analysis of the Damage Parameter on a Simplified Cylinder Head of a Variable Compression Rate Engine

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***Abstract:-*** This work is a contribution to the mechanical and thermomechanical analysis of the damage parameter of a compression ratio engine through the study of the cylinder head. The numerical method through COMSOL multiphysics, MATLAB SIMULINK software and the analytical method through the Love-Kirchhoff theory of thermal conduction were the only methods used. From the Navier method, the Lagrange equation was solved in order to obtain the mechanical deformation, the method of separation of the variables allowing to solve the Laplace equation made it possible to obtain the thermal conduction field of the cylinder head. This led to the characterization of the VON MISES stress and the damage parameter. In addition, the various simulations also made it possible to provide information on the said constraint and the said parameter. The outcome of these analyzes showed that the damage parameter is a worrying factor given its value, although the energy efficiency of the engine with variable compression ratio is significant according to numerous studies on the subject. Knowledge of this parameter and its mastery will make it possible to better understand all the conceptual and technological phases of this engine, the latter which will bring more efficiency in terms of energy, mechanics and thermomechanics. The outcome of these analyzes showed that the damage parameter is a worrying factor given its value, although the energy efficiency of the engine with variable compression ratio is significant according to numerous studies on the subject. Knowledge of this parameter and its mastery will make it possible to better understand all the conceptual and technological phases of this engine, the latter which will bring more efficiency in terms of energy, mechanics and thermomechanics. The outcome of these analyzes showed that the damage parameter is a worrying factor given its value, although the energy efficiency of the engine with variable compression ratio is significant according to numerous studies on the subject. Knowledge of this parameter and its mastery will make it possible to better understand all the conceptual and technological phases of this engine, the latter which will bring more efficiency in terms of energy, mechanics and thermomechanics.

***Keywords***: *Damage, COMSOL multiphysics, MATLAB, Love-Kirchhoff, Navier, VON MISES.*

## 1. Introduction

A heat engine is an engine that transforms thermal energy into mechanical energy and all damage of any kind whatsoever constitutes what is called damage. Studies on the performance of the thermal engine and the phenomena of damage have been carried out and continue to arouse interest for scientific development. In terms of modeling energy performance, MERABET ABDERREZAK [1] has contributed to the study of exchange phenomena in an atmospheric diesel engine, essentially based on the modeling and calculation of factors impacting the performance of a diesel engine. variable compression ratio, concluding that variable compression ratio improves performance. Adrian CLENCI and Pierre PODEVIN [2] have concluded that the variable compression ratio offers hope for a 35% fuel saving at partial loads for supercharged automotive engines with small displacements and high specific powers, despite the advantages and disadvantages presented by the variable compression ratio engine[12]. In terms of damage phenomena, in January 1943 the one-day-old Tanker T2 SS Schnactady cracked at sea, in January 1998 a ship sank in newfoundland. In our companies, certain failures of unknown causes have the effect of reducing engine performance. Is this how a question arises? Does the energy performance of a variable compression ratio engine have an impact on its damage? A mechanical then thermomechanical study of the damage parameter will then be carried out both analytically and numerically.

## 2. Methods

### 2.1 Analytical Method

#### 2.1.1 Physical Modeling of the Problem

The cylinder head of our variable compression ratio engine in the context of our study can be likened to a thin plate with the following representation:

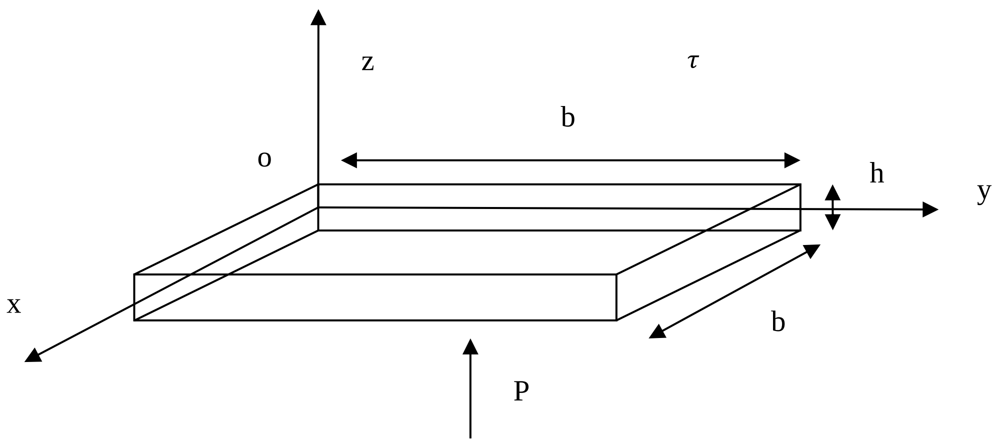


**Fig.1 Simplified shape of a cylinder head**

#### 2.1.2 Mathematical Modeling of the Problem

#### 2.1.2.1 Thermal Modeling of the Cylinder Head

The cylinder head is made of a homogeneous and isotropic material. The cylinder head is also made of a heat conducting material. Assuming that the regime is permanent, we have:

$$\rho_0 c_v \frac{\partial \tau}{\partial t} = K_0 \Delta\tau \Leftrightarrow \Delta\tau = \frac{\rho_0 c_v}{K_0}\frac{\partial \tau}{\partial t} \quad \text{Eq (1)}$$

With $\tau = \tau(x, y, z) \Leftrightarrow \frac{\partial^2 \tau}{\partial x^2} + \frac{\partial^2 \tau}{\partial y^2} + \frac{\partial^2 \tau}{\partial z^2} = 0$ Eq (2)

Equation (2) is Laplace's equation.

#### 2.1.2.2 Mechanical Modeling of the Cylinder Head

#### 2.1.2.2.1 Modeling of the Deformation of the Cylinder Head

From [12] we have :

$$\boldsymbol{\nabla^4 w = \frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{P}{D}} \quad \text{Eq (3)}$$

This the expression of the deformation is the Lagrange equation.

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$$\boldsymbol{\nabla^4 w = \frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{P}{D}}$$ Eq (4)

In general mechanics [12], in the automobile field, the so-called light alloy aluminum alloy can be used with respect to their very low density compared to common metals. We can take the aluminum alloy AS12U whose chemical designation is AlSi12Cu, the density, the modulus of elasticity, the mechanical resistance the Poisson's ratio2.70 $g/cm^3$74 000 $MPa$300 $MPa$, 0.33.

**2.1.2.2.2 Mechanical Modeling of the Von Mises Stress of the Cylinder Head**

The plane stresses of our cylinder head in the form of a thin plate are:

$$\sigma_x = -\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right)$$ Eq(5)

$$\sigma_y = -\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)$$ Eq (6)

$$\sigma_{xy} = -\frac{Ez}{1+\nu}\left(\frac{\partial^2 w}{\partial x \partial y}\right)$$ Eq(7)

The main constraints are:

$$\sigma_I = \frac{1}{2}\left[(\sigma_x + \sigma_y) - \sqrt{(\sigma_x - \sigma_y)^2 + 4{\sigma_{xy}}^2}\right]$$ Eq(8)

$$\sigma_I = \frac{1}{2}\left[\left(-\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) - \frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)\right) - \sqrt{\left(-\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) + \frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)\right)^2 + 4 - \frac{Ez}{1+\nu}\left(\frac{\partial^2 w}{\partial x \partial y}\right))^2}\right]$$ Eq (9)

$$\sigma_{II} = \sigma_z$$ Eq (10)

$$\sigma_{II} = 0$$ Eq (11)

$$\sigma_{III} = \frac{1}{2}\left[(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4{\sigma_{xy}}^2}\right]$$ Eq (12)

$$\sigma_{III} = \frac{1}{2}\left[\left(-\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) - \frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)\right) + \sqrt{\left(-\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right) + \frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right)\right)^2 + 4(-\frac{Ez}{1+\nu}\left(\frac{\partial^2 w}{\partial x \partial y}\right))^2}\right]$$ Eq (13)

Thus with the previous expressions, according to VON MISES the stress of the cylinder head is:

$$\sigma_{VONMISES} = \sqrt{\frac{1}{2}[(\sigma_{III} - \sigma_I)^2 + (\sigma_{II} - \sigma_I)^2 + (\sigma_{III} - \sigma_{II})^2]}$$ Eq (14)

$$\boldsymbol{\sigma_{MECAVONMISES} = \sqrt{\frac{1}{2}[(\sigma_{III} - \sigma_I)^2 + {\sigma_I}^2 + {\sigma_{III}}^2]}}$$ Eq (15)

**2.1.2.2.3 Mechanical Modeling of Cylinder Head Damage**

Given this parameter, the relationship between the theoretical and practical stress is as follows:$d_{méca}$

$$\sigma_{théorique} = (1 - d_{méca})\sigma_{pratique}$$ Eq (16)

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$$d_{m\acute{e}ca} = 1 - \frac{\sigma_{th\acute{e}orique}}{\sigma_{pratique}}$$ Eq (17)

$$d_{m\acute{e}ca} = \mathbf{1} - \frac{\boldsymbol{\sigma_{MECAVONMISES}}}{\boldsymbol{\sigma_e}}$$ Eq (18)

**2.1.2.3 Thermomechanical Modeling of the Von Mises Stress of the Cylinder Head**

It is expressed as follows:

$$\boldsymbol{\sigma_{THERMOMECAVONMISES} = \sigma_{MECAVONMISES} + K_0 \Delta\tau}$$ Eq (19)

**2.1.2.4 Thermomechanical Modeling of Cylinder Head Damage**

Given this parameter, the relationship between the theoretical and practical stress is as follows: $d_{thermom\acute{e}ca}$

$$\sigma_{th\acute{e}orique} = (1 - d_{thermom\acute{e}ca})\sigma_{pratique}$$ Eq (20)

$$d_{thermom\acute{e}ca} = 1 - \frac{\sigma_{th\acute{e}orique}}{\sigma_{pratique}}$$ Eq (21)

$$\boldsymbol{d_{thermom\acute{e}ca} = 1 - \frac{\sigma_{THERMOMECAVONMISES}}{\sigma_e}}$$ Eq (22)

**2.1.3 Methods for Resolving Certain Analytical Models**

**2.1.3.1 Method of Separation of Variables With A View To Resolving the Thermal Conduction Equation (Laplace Equation)**

Using the method of separation of variables, we assume that the solution to equation (2) is:

$$\tau(x, y, z) = X(x)Y(y)Z(z)$$ Eq (23)

Using equation (3), we have the expansions of the following partial derivatives:

$$\left.\begin{array}{l} \frac{\partial \tau}{\partial x} = YZ\frac{\partial X}{\partial x} \Rightarrow \frac{\partial^2 \tau}{\partial x^2} = YZ\frac{\partial^2 X}{\partial x^2} \\ \frac{\partial \tau}{\partial y} = XZ\frac{\partial Y}{\partial y} \Rightarrow \frac{\partial^2 \tau}{\partial y^2} = XZ\frac{\partial^2 Y}{\partial y^2} \\ \frac{\partial \tau}{\partial z} = XY\frac{\partial Z}{\partial z} \Rightarrow \frac{\partial^2 \tau}{\partial z^2} = XY\frac{\partial^2 Z}{\partial z^2} \end{array}\right\}$$ Eq(24)

Equation (24) in equation (2) gives:

$$YZ\frac{\partial^2 X}{\partial x^2} + XZ\frac{\partial^2 Y}{\partial y^2} + XY\frac{\partial^2 Z}{\partial z^2} = 0$$ Eq (25)

By dividing $XYZ$ by equation (25) we have:

$$\frac{1}{X}\frac{\partial^2 X}{\partial x^2} + \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} + \frac{1}{Z}\frac{\partial^2 Z}{\partial z^2} = 0$$ Eq (26)

The variables are independent variables, so equation (26) exists if and only if each of the three terms of this equation is constant. $x, y, z$

**Case:** $\frac{1}{X}\frac{\partial^2 X}{\partial x^2} = m^2, \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} = n^2, m, n \in \mathbb{R}$

$$\left\{\begin{array}{l} \frac{1}{X}\frac{\partial^2 X}{\partial x^2} = m^2 \Rightarrow \frac{\partial^2 X}{\partial x^2} = m^2 X \\ \Rightarrow \frac{\partial^2 X}{\partial x^2} - m^2 X = 0 \\ \Rightarrow X(x) = Ae^{mx} + Be^{-mx},\ A, B \in \mathbb{R} \\ \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} = n^2 \Rightarrow \frac{\partial^2 Y}{\partial y^2} = n^2 Y \\ \Rightarrow \frac{\partial^2 Y}{\partial y^2} - n^2 Y = 0 \\ \Rightarrow Y(y) = A'e^{ny} + B'e^{-ny},\ A', B' \in \mathbb{R} \end{array}\right.$$ Eq (27)

By substituting the values $\frac{1}{X}\frac{\partial^2 X}{\partial x^2}, \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2}$ in equation (27), we have:

$$-\frac{1}{Z}\frac{\partial^2 Z}{\partial z^2} = m^2 + n^2 \quad \text{Eq (28)}$$

By setting $\lambda^2 = m^2 + n^2$ we have:

$$\begin{cases} \lambda^2 = -\frac{1}{Z}\frac{\partial^2 Z}{\partial z^2} \\ \Rightarrow \frac{\partial^2 Z}{\partial z^2} = -\lambda^2 Z \\ \Rightarrow \frac{\partial^2 Z}{\partial z^2} + \lambda^2 Z = 0 \\ \Rightarrow Z(z) = A''\cos(\lambda z) + B''\sin(\lambda z),\ A'', B'' \in \mathbb{R} \end{cases} \quad \text{Eq (29)}$$

Plugging the values $X, Y, Z$ into equation (23), the general solution is:

$$\tau(x,y,z) = (Ae^{mx} + Be^{-mx})(A'e^{ny} + B'e^{-ny})(A''\cos(\lambda z) + B''\sin(\lambda z)) \quad \text{Eq (30)}$$

The boundary conditions are:

$$\tau\left(x,y,\frac{h}{2}\right) = T_g,\ \ T_g\ \textit{is the exhaust temperature} \quad \text{Eq (31)}$$

$$\tau\left(x,y,-\frac{h}{2}\right) = T_a, T_a\ \textit{is the inlet temperature} \quad \text{Eq (32)}$$

By applying the boundary condition of equation Eq (31) to equation Eq (30), we have:

$$(Ae^{mx} + Be^{-mx})(A'e^{ny} + B'e^{-ny})(A''\cos(\lambda z) + B''\sin(\lambda z)) = T_{g_a} \Rightarrow (Ax + B) = 1, (Ae^{mx} + Be^{-mx})(A'e^{ny} + B'e^{-ny})\left(A''\cos\left(\lambda\frac{h}{2}\right) + B''\sin\left(\lambda\frac{h}{2}\right)\right) = T_g \quad \text{Eq (33)}$$

By applying the boundary condition of equation Eq (32) to equation Eq (30), we have:

$$(Ae^{mx} + Be^{-mx})(A'e^{ny} + B'e^{-ny})(A''\cos(\lambda z) + B''\sin(\lambda z)) = T_a \Rightarrow (Ax + B) = 1, (Ae^{mx} + Be^{-mx})(A'e^{ny} + B'e^{-ny})\left(A''\cos\left(\lambda\left(-\frac{h}{2}\right)\right) + B''\sin\left(\lambda\left(-\frac{h}{2}\right)\right)\right) = T_a \quad \text{Eq (34)}$$

The boundary conditions can also be expressed in this way:

$$\begin{cases} x = 0, A + B = 1 \Rightarrow B = 1 - A \\ x = a, Ae^{ma} + Be^{-ma} = 1 \Rightarrow A = \frac{e^{ma}-1}{e^{2ma}-1} \Rightarrow B = \frac{e^{2ma}-e^{ma}}{e^{2ma}-1} \end{cases} \quad \text{Eq (35)}$$

$$\begin{cases} y = 0, A' + B' = 1 \Rightarrow B' = 1 - A' \\ y = a, A'e^{ma} + B'e^{-na} = 1 \Rightarrow A' = \frac{e^{na}-1}{e^{2na}-1} \Rightarrow B' = \frac{e^{2na}-e^{na}}{e^{2na}-1} \end{cases} \quad \text{Eq (36)}$$

$$\begin{cases} z = -h/2, A''\cos(\lambda(-\frac{h}{2})) + B''\sin(\lambda(-\frac{h}{2})) = T_a \\ z = h/2, A''\cos(\lambda\frac{h}{2}) + B''\sin(\lambda\frac{h}{2}) = T_g \Rightarrow A'' = \frac{T_g+T_a}{2\cos(\lambda\frac{h}{2})}, B'' = \frac{T_g-T_a}{2\sin(\lambda\frac{h}{2})} \end{cases} \quad \text{Eq (37)}$$

The temperature field is therefore:

$$\boldsymbol{\tau(x,y,z)} = \left(\left(\frac{e^{ma}-1}{e^{2ma}-1}\right)e^{mx} + \left(\frac{e^{2ma}-e^{ma}}{e^{2ma}-1}\right)e^{-mx}\right)\left(\left(\frac{e^{na}-1}{e^{2na}-1}\right)e^{ny} + \left(\frac{e^{2na}-e^{na}}{e^{2na}-1}\right)e^{-ny}\right)\left(\left(\frac{T_g+T_a}{2\cos\left(\lambda\frac{h}{2}\right)}\right)\cos(\lambda z) + \left(\frac{T_g-T_a}{2\sin\left(\lambda\frac{h}{2}\right)}\right)\sin(\lambda z)\right) \quad \text{Eq (38)}$$

**2.1.3.2 Navier Method for Solving the Lagrange Equation**

Lagrange's equation was solved in 1820 by Navier for the case of a rectangular plate simply supported on its four edges.

From [12] we have:

$$w(x,y) = \sum_{m=1}^{+\infty}\sum_{n=1}^{+\infty}\frac{q_{mn}}{D\pi^4\left(\frac{m^2}{a^2}+\frac{n^2}{a^2}\right)^2}\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{a}\right) \quad \text{Eq (39)}$$

### 2.2 Numerical Method

#### 2.2.1 Simulation with Matlab

MATLAB is a software allowing to carry out scientific calculations and engineering simulations by the means of the sub programs previously elaborated. Thus the expressions of the temperature resulting from the method of separation of the variables, the deformation resulting from the method of Navier and the parameter of damage are calculated. Several other simulations are made in the same orientation allowing to appreciate the evolution of all the parameters related to the deformation and the damage. The calculationflowcharts are as follows:

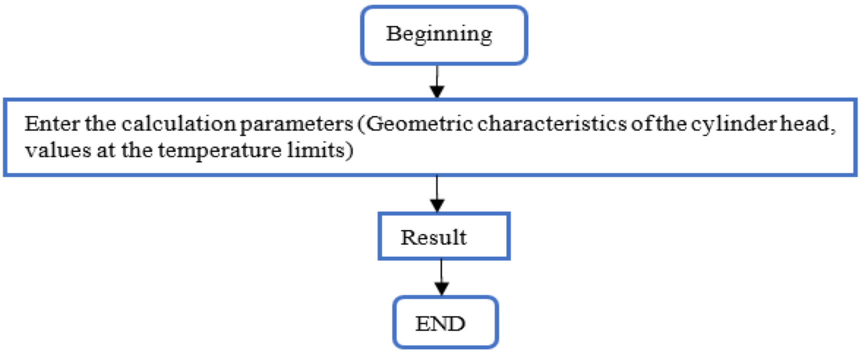



**Fig.2 Temperature calculation flowchart in MATLAB**

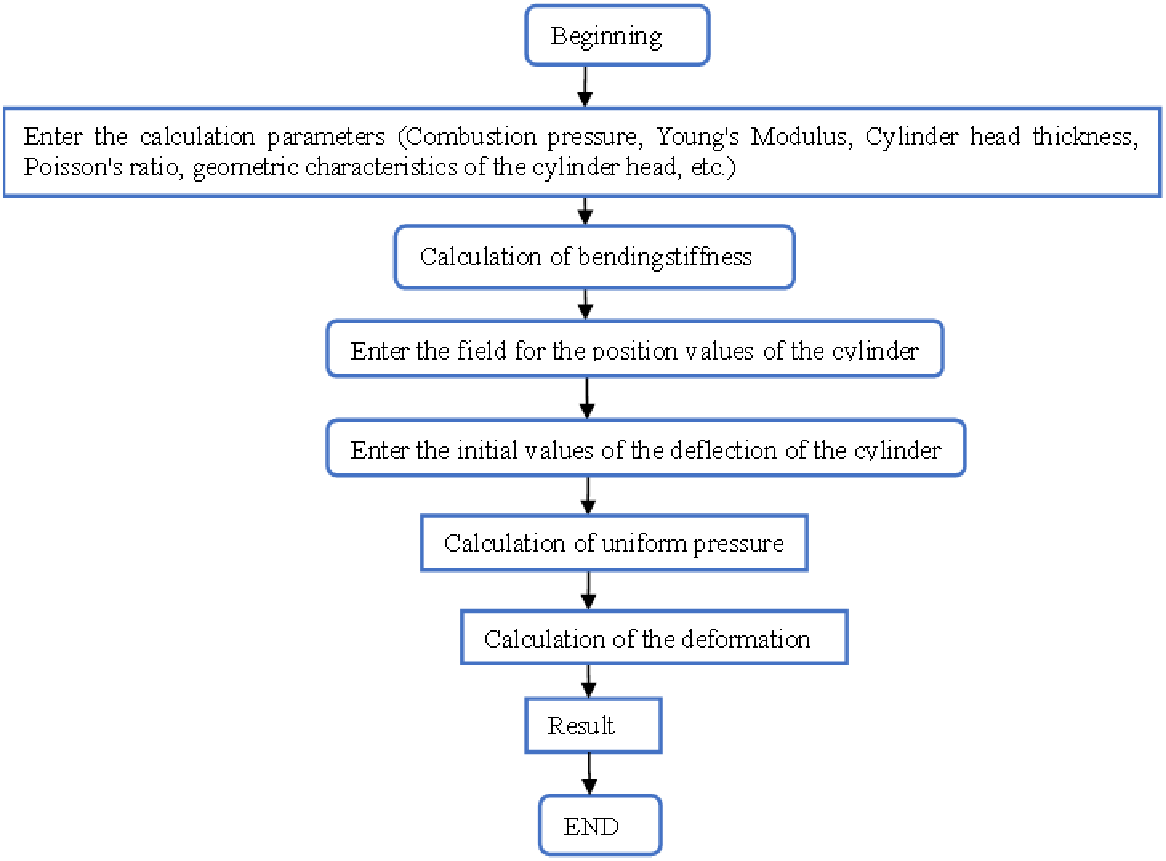



**Fig.3 Deformation calculation flowchart in MATLAB**

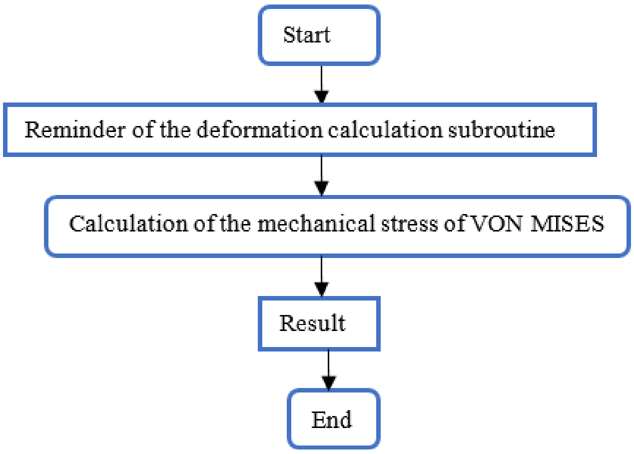



**Fig.4 Flow chart for calculating the VON MISES stress in MATLAB**

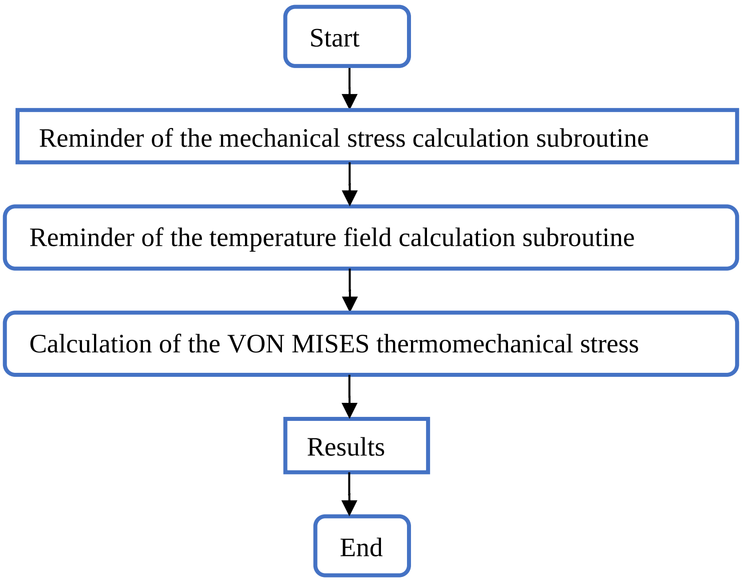



**Fig.5 Flowchart for calculating the thermomechanical stress of VON MISES under MATLAB**

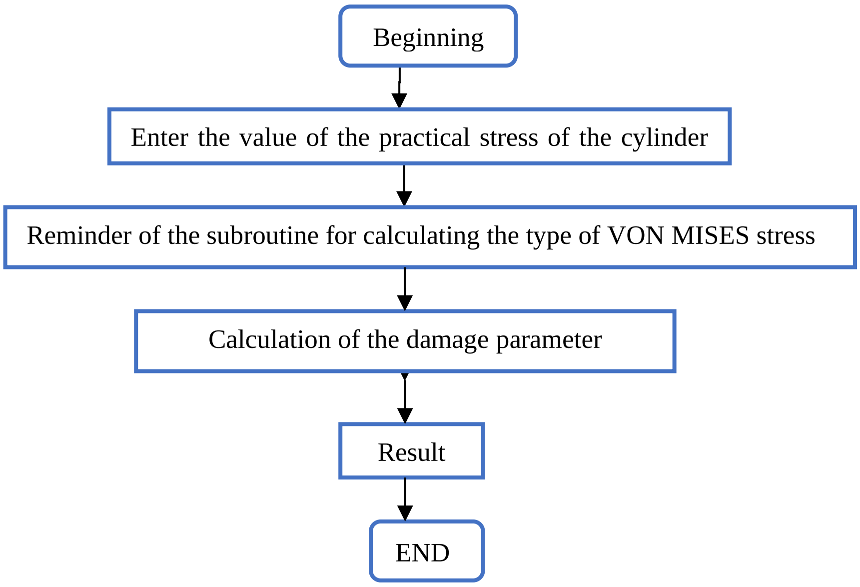



**Fig.6 Flowchart of calculation of the parameter of damage under MATLAB**

Thus the subroutines under MATLAB according to the flowcharts of the figures, Fig.2, Fig.3, Fig.4, Fig.5, Fig.6, will provides us with practical data.

### 2.2.2 Simulation with Comsol Multiphysics

The COMSOL Multiphysics software is a scientific software which makes it possible to model a material system by integrating all the physical parameters surrounding it. The values of the deformation, the VON MISES stress and other surrounding factors were obtained by computer simulation. The calculationflowchartis as follows:

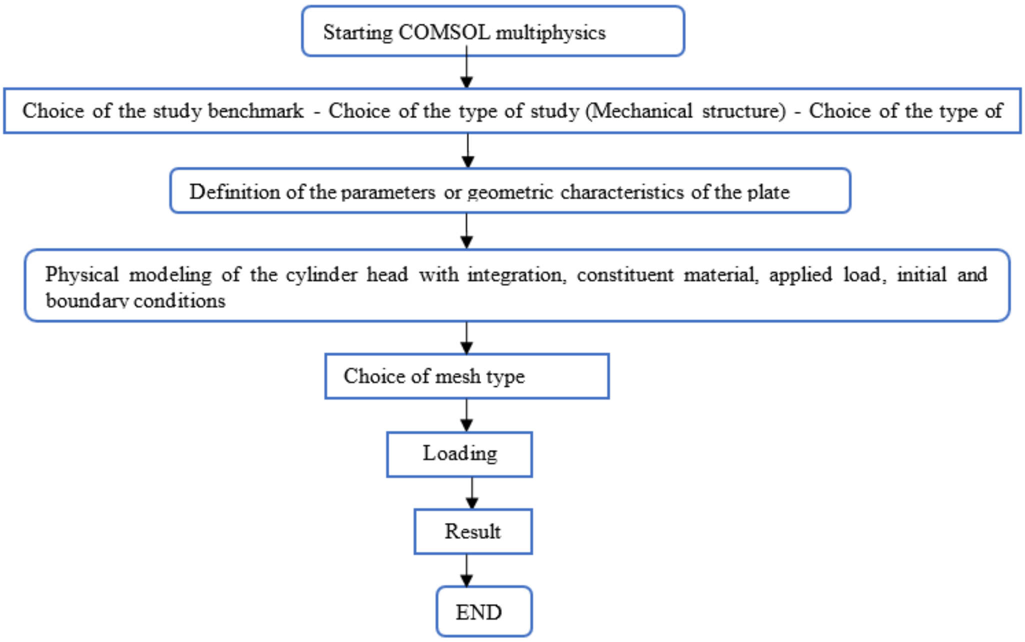



**Fig.7 Calculation flowchart under COMSOL multiphysics**

Thus the sub-simulation under COMSOL according to the flowchart of the figure, Fig. 7, will provides us with practical data.

## 3. Results and Discussion

A subroutine developed under MATLAB to calculate the temperature field of the cylinder head and a simulation under the COMSOL Multiphysics software gives this:

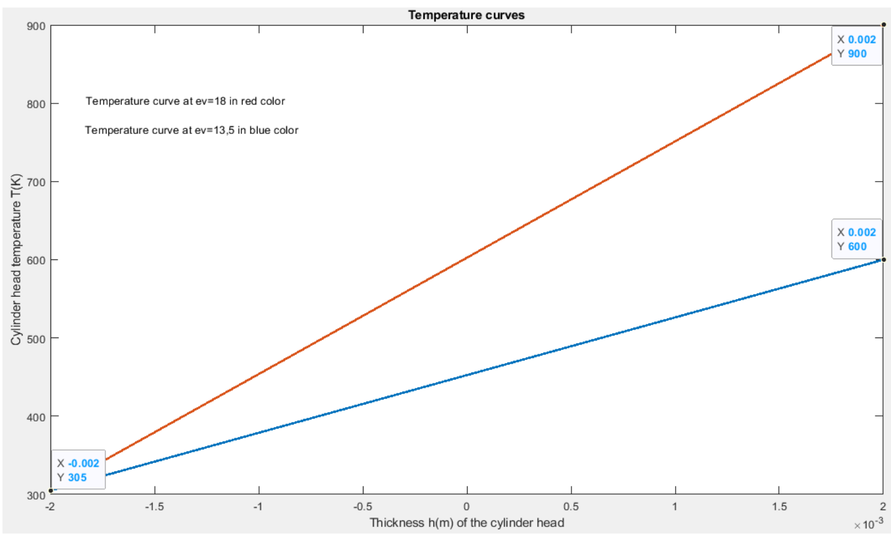
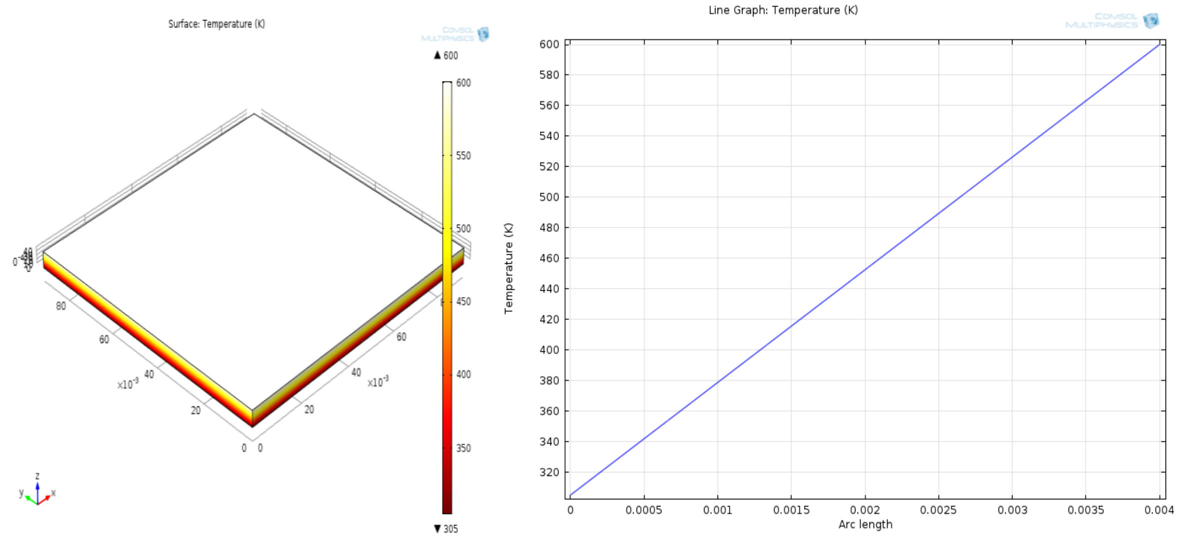



**Fig.8 Cylinder head temperature curves in MATLAB**

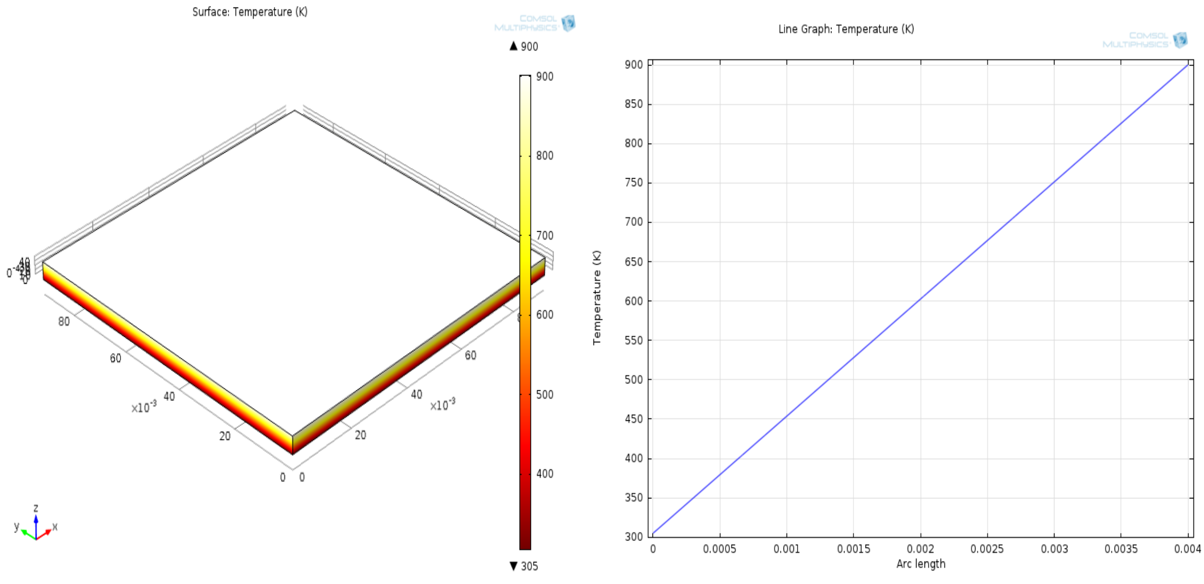
The figure Fig.8 presents the behavior of the temperature of the cylinder head after compilation of the subroutines under MATLAB

A simulation under COMSOL Multiphysics, we have:




**(a)** **(b)**

**Fig.9 Temperature curves of the cylinder head at intake, (a) Evolution of the temperature of the cylinder head in 3D, (b) Temperature curve according to the thickness**




**(a)** **(b)**

**Fig.10 Temperature curves of the cylinder head at the exhaust, (a) Evolution of the temperature of the cylinder head in 3D, (b) Temperature curve according to the thickness**

The figures Fig.9 and Fig.10 show the behavior of the temperature of the cylinder head after simulation under COMSOL.

Figure Fig.11illustrates the representation according to the extreme compression ratios of the deformations:

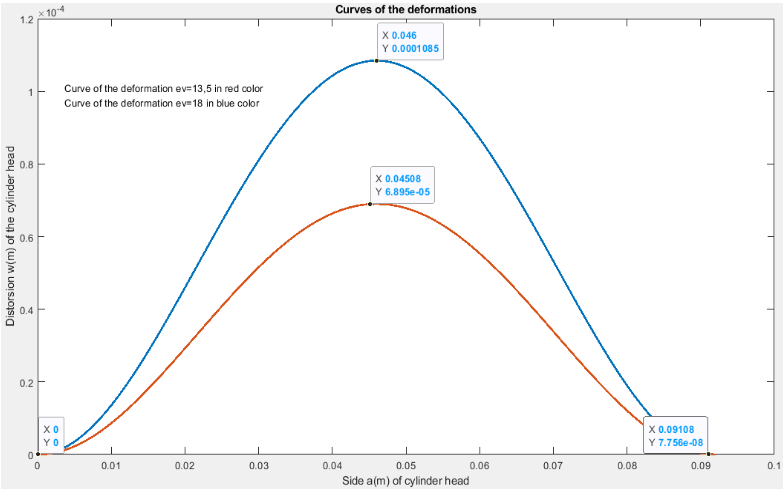



**Fig.11 Curve of the different deflections from a sub-program developed in MATLAB$\varepsilon_v = 13,5$ *and* $\varepsilon_v = 18$**

According to the subroutine developed under MATLAB, at$\varepsilon_v = 13{,}5$ the yoke bent to the position, the yoke bent to the position according to the mark in Fig.12. $w_{min} = 6{,}902.10^{-5}m$ $(0{,}046\ m, 0{,}046\ m)$ $\varepsilon_v = 18$ $w_{max} = 10{,}85.10^{-5}m$ $(0{,}046\ m, 0{,}046\ m)$

Timoshenko S and Woinowsky-Krieger S (1959), presented analytical solutions of the deformations of the plates requested in bending according to certain requests. Thus a square plate simply supported with a load applied uniformly, presents a deformation in the form$w_{ref} = 4{,}062.10^{-3}\frac{qa^4}{D}$, q being the uniformly distributed load, a the side of the plate, D the bending stiffness[12]. So we have:

A with P= $105000\ N/m^2.\varepsilon_v = 13{,}5$ $w_{ref} = 6{,}8988.10^{-5}m$

Has with$P = 165000\ N/m^2$ $.\varepsilon_v = 18$ $w_{ref} = 10{,}841.10^{-5}m$

Discrepancies are observed between the deformation resulting from the sub-program and the reference deformation from to$0.0464\ \%$ $\varepsilon_v = 13{,}5$, of$0.0829\ \%$ To$\varepsilon_v = 18$. These deviations being less than, we can say that the results from the sub-program are satisfactory. $0{,}5\ \%$

The simulation under the COMSOL software presents the values of deformations and stresses of VON MISES in the form of the following figures:

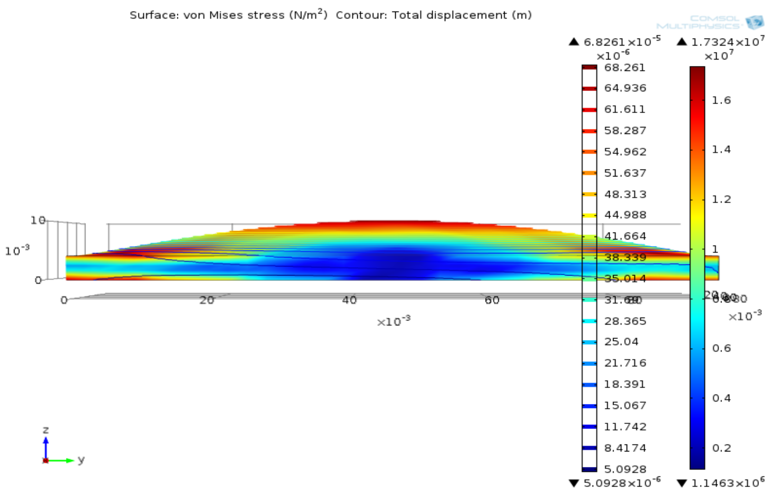



**Fig.12 VON MISES deformation and stress curves from the simulation under COMSOL multiphysics$\varepsilon_v = 13,5$**

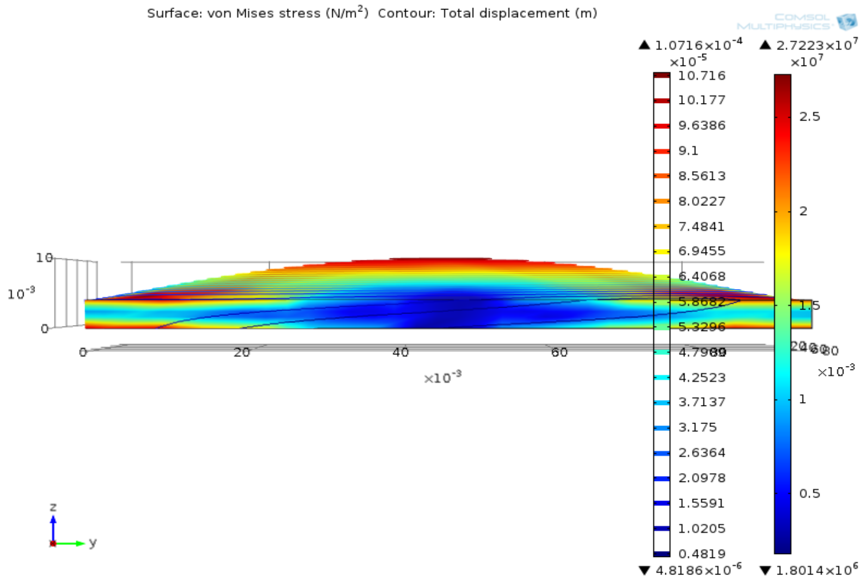



**Fig.13 VON MISES deformation and stress curves from the simulation under COMSOL multiphysics $\varepsilon_v = 18$**

The figures Fig.12 and Fig.13 show the behavior of the deformations and the VON MISES stresses of the cylinder head after simulation under COMSOL

According to the previous curves from the COMSOL multiphysics software, the maximum deformation values are as follows:

A with P= $105000\ N/m^2 . \varepsilon_v = 13{,}5\ w_{min} = 6{,}8261.10^{-5} m$

Has with$P = 165000\ N/m^2 . \varepsilon_v = 18\ w_{max} = 10{,}716.10^{-5} m$

The differences between the deformation resulting from the MATLAB sub-program and the COMSOL multiphysics software are from to1,0996 % $\varepsilon_v = 13{,}5$, of1,2350 % To$\varepsilon_v = 18$. Thus the results of the subroutine and of the COMSOL multiphysics software are satisfactory with deviations less than.1,5 %

The simulation under MATLAB of the subroutine for calculating the stress of VO N MISES presents the following curves:

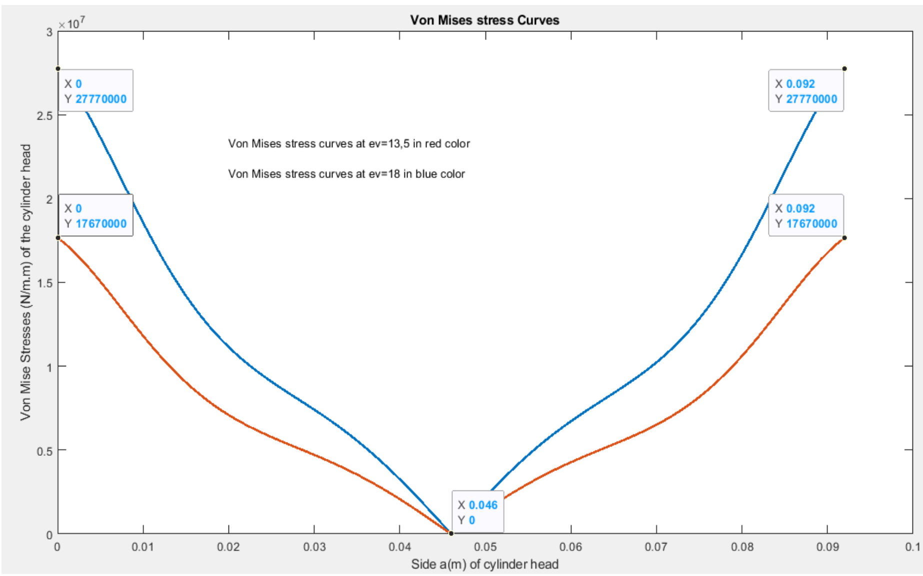



**Fig.14 VON MISES stress curves at and from simulation under MATLAB$\varepsilon_v = 13,5 \varepsilon_v = 18$**

According to the previous curves of the VON MISES stresses resulting from the simulation under MATLAB, the maximum values are as follows:

A with P= 105000 $N/m^2.\varepsilon_v = 13{,}5$ $\sigma_{VONMISESmin} = 1{,}767.10^7\ N/m^2$

Has with= 165000 $N/m^2$ $.\varepsilon_v = 18$ $\sigma_{VONMISESmax} = 2{,}777.10^7\ N/m^2$

Once again, according to the previous curves from the COMSOL multiphysics software, the maximum stress values of VON MISES are as follows:

A with P= 105000 $N/m^2.\ \varepsilon_v = 13{,}5$ $\sigma_{VONMISESmin} = 1{,}7324.10^7\ N/m^2$

Has with$P = 165000\ N/m^2.\ \varepsilon_v = 18$ $\sigma_{VONMISESmax} = 2{,}7223.10^7\ N/m^2$

The differences between the VON MISES constraint resulting from the MATLAB subroutine and the COMSOL multiphysics software are from to1,958 % $\varepsilon_v = 13{,}5$, of1,969 % To$\varepsilon_v = 18$. Thus the results of the subroutine and of the COMSOL multiphysics software are satisfactory with deviations less than.1,5 %

Having the values of the stresses of VON MISES, the simulation of the subroutine of the parameter of damage under MATLAB presents the following curves:

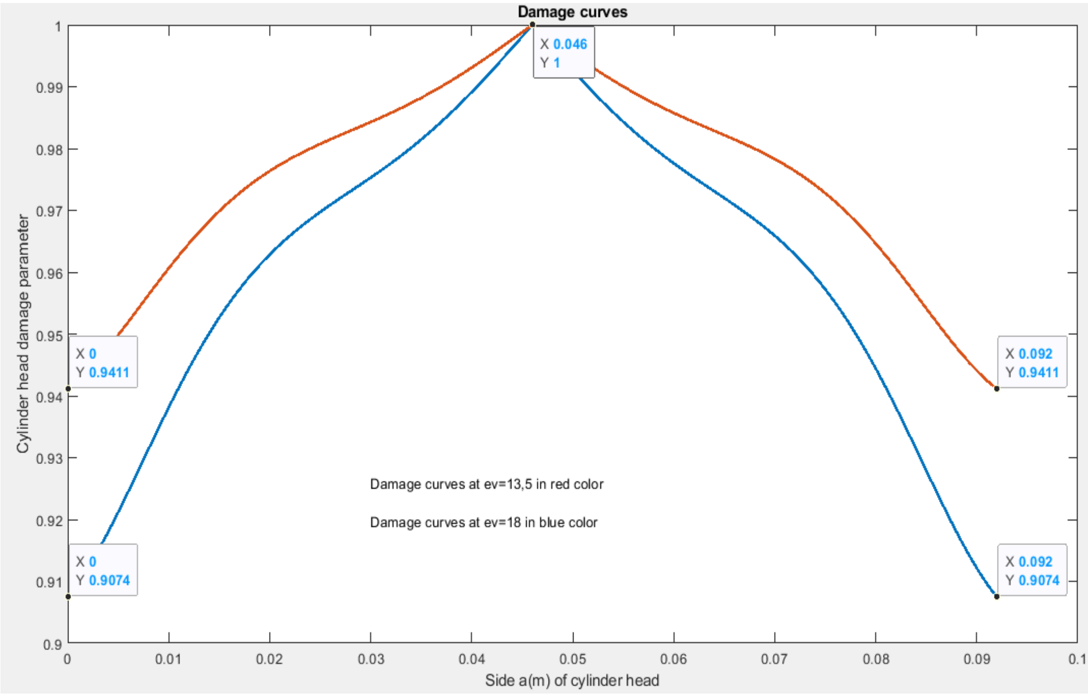



**Fig.15 Curves of the damage parameter à and à from the simulation in MATLAB$\boldsymbol{\varepsilon_v = 13,5\varepsilon_v = 18}$**

The figures Fig.14 and Fig.15 present the behavior of the VON MISES stresses and cylinder head damage parameter after compilation under MATLAB.

According to the preceding curves of the parameter of damage resulting from the simulation under MATLAB, the values are the following ones:

A with P= 105000 $N/m^2.\varepsilon_v = 13{,}5$ $d_{min} = 0{,}0589$

Has with $P = 165000\ N/m^2\varepsilon_v = 18\ d_{max} = 0{,}0926$

It is observed that the cylinder head bends and damages more in the center of the plate and that these bending and damage factors are more intense at a compression ratio compared to a compression ratio. Although the variable compression ratio engine improves performance, the deformation and damage parameter of its cylinder head are large, therefore increasing its risk of damage.$\varepsilon_v = 18$ $\varepsilon_v = 13{,}5$

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By varying the combustion pressure between its minimum and maximum value at a few points, we have the space of values of the damage parameters in the form of the following table:

**Table 1. Some maximum values of the damage parameters depending on the combustion pressures resulting from a subroutine calculating the damage parameter under MATLAB**

| Some values of the maximum combustion pressure (N/m2) | 105000 | 120000 | 135000 | 150000 | 165000 |
|---|---|---|---|---|---|
| Damage Parameter | 0.0589 | 0.0673 | 0.0757 | 0.0841 | 0.0926 |

Thus the parameter of damage according to the maximum pressure is represented as follows:

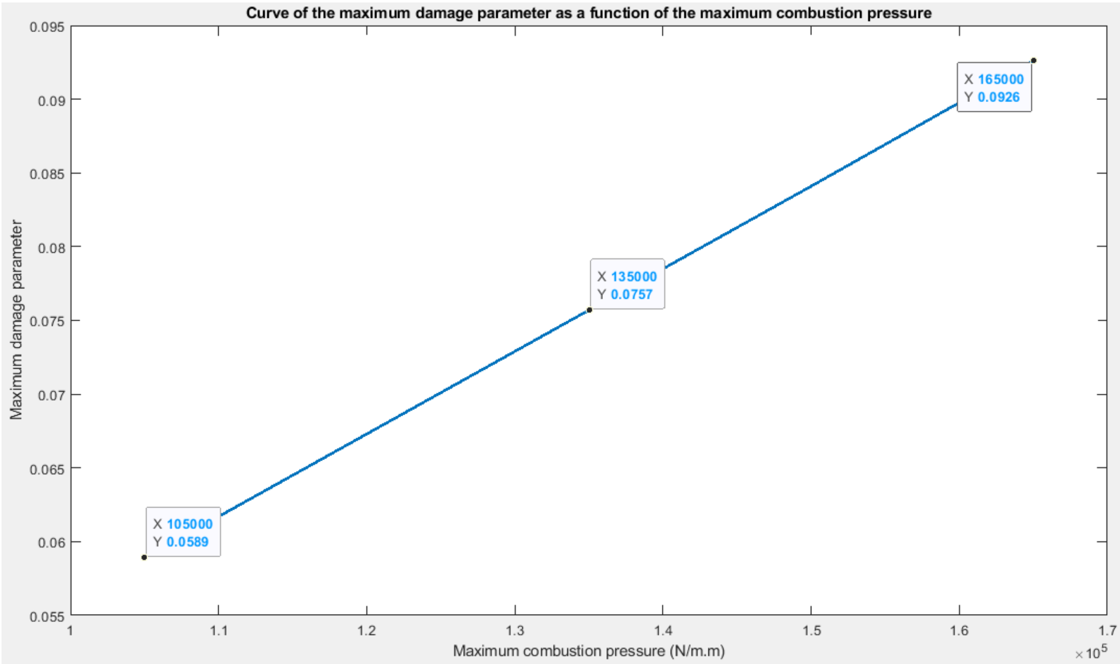


**Fig.16 Curve of the maximum damage parameter as a function of the maximum combustion pressure taken from MATLAB**

The function resulting from curve is a linear line of expression:

$\boldsymbol{d = 5,6.10^{-7}P + 9,9462.10^{-5}}$Eq (40)

By varying the combustion pressure between its minimum and maximum value at a few points, we have the space of the values of the deformations in the form of the following table:

**Table 2. Some values of the deformation as a function of the combustion pressures taken from a subroutine calculating the deformation in MATLAB**

| Some values of the maximum combustion pressure (N/m2) | 105000 | 120000 | 135000 | 150000 | 165000 |
|---|---|---|---|---|---|
| Maximum deformations (m) | $6,902.10^{-5}$ | $7,8875.10^{-5}$ | $8.8734.10^{-5}$ | $9.8594.10^{-5}$ | $10.85.10^{-5}$ |

Thus the maximum combustion pressure as a function of the maximum deformation is represented as follows:

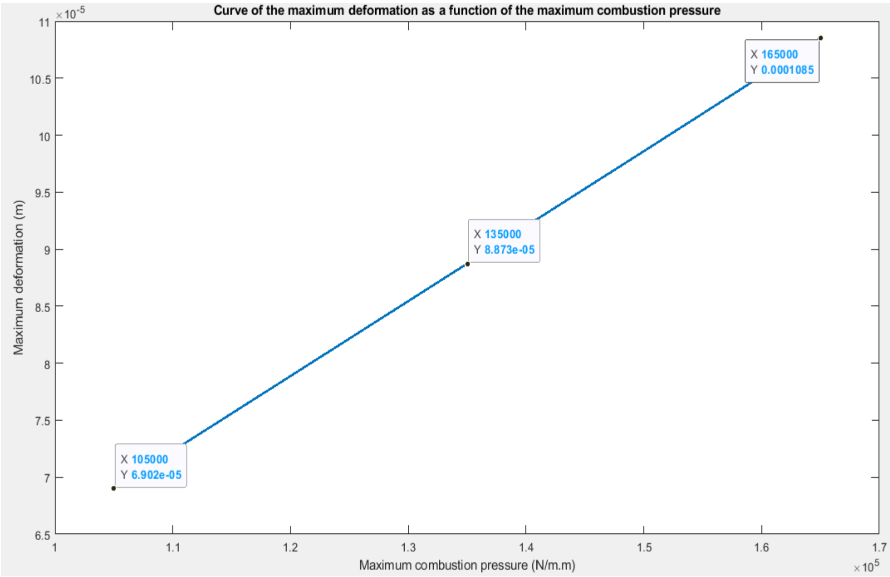


**Fig.17 Curve of the maximum deformation as a function of the maximum combustion pressure from MATLAB**

The function resulting from curve is a linear line of expression:

$\boldsymbol{w = 6,5699.10^{-10}d + 3,674710^{-8}}$Eq (41)

From the two previous relations we have:

$\boldsymbol{d = 852.3828w + 6,8140.10^{-5}}$Eq (42)

The curve associated with the previous relationship is as follows:

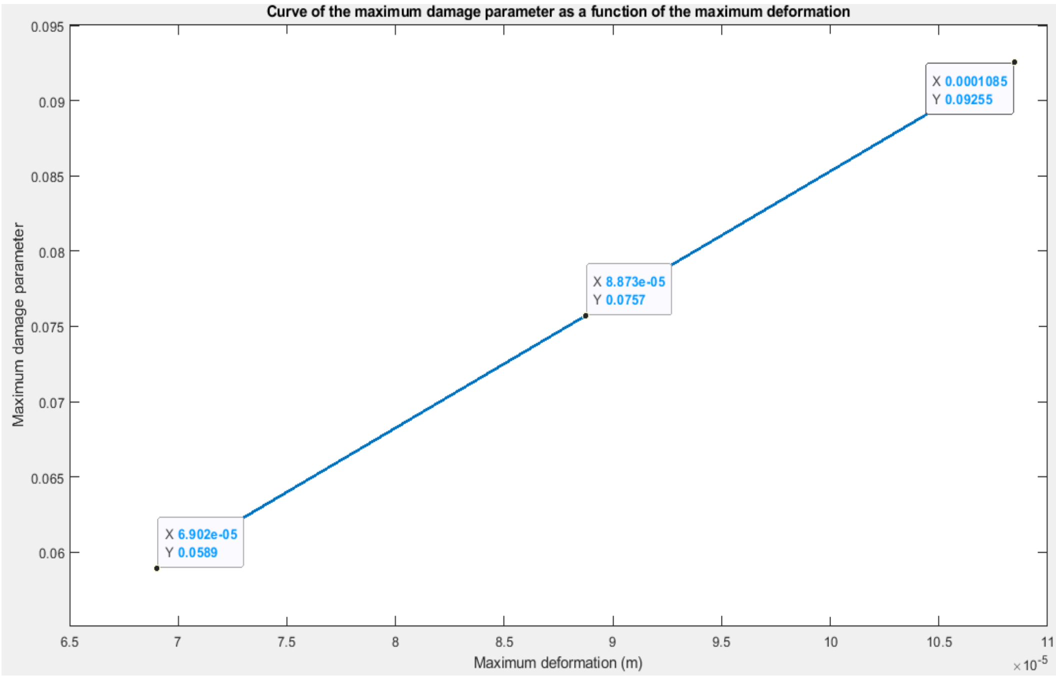


**Fig.18 Curve of the maximum damage parameter as a function of the maximum deformation from MATLAB**

The figures Fig.16, Fig.17, Fig.18, present the behavior of the mechanical parameters of the cylinder head after compilation under MATLAB.

It is noted that the more the deformation evolves, the damage increases. At maximum combustion pressure, i.e. with a damage parameter of*0.09255*, this damage has a deviation of*57.13%*with that at the minimum combustion pressure, i.e. 0.0589. Once again it appears that the improvement in the energy efficiency of our variable compression ratio engine is reflected in a higher risk of damage to our cylinder head in its simplified form.

By simulation on the COMSOL Multiphysics software, we have the following VON MISES thermomechanical constraints:

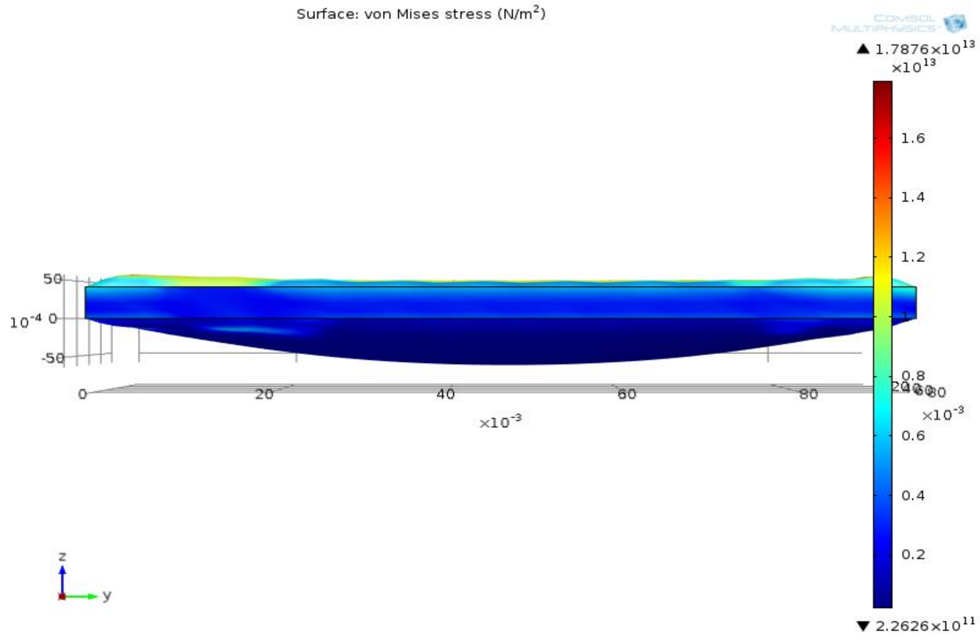


**Fig.19 VON MISES thermomechanical stress curve from the simulation under COMSOL multiphysics$\varepsilon_v = 13,5$**

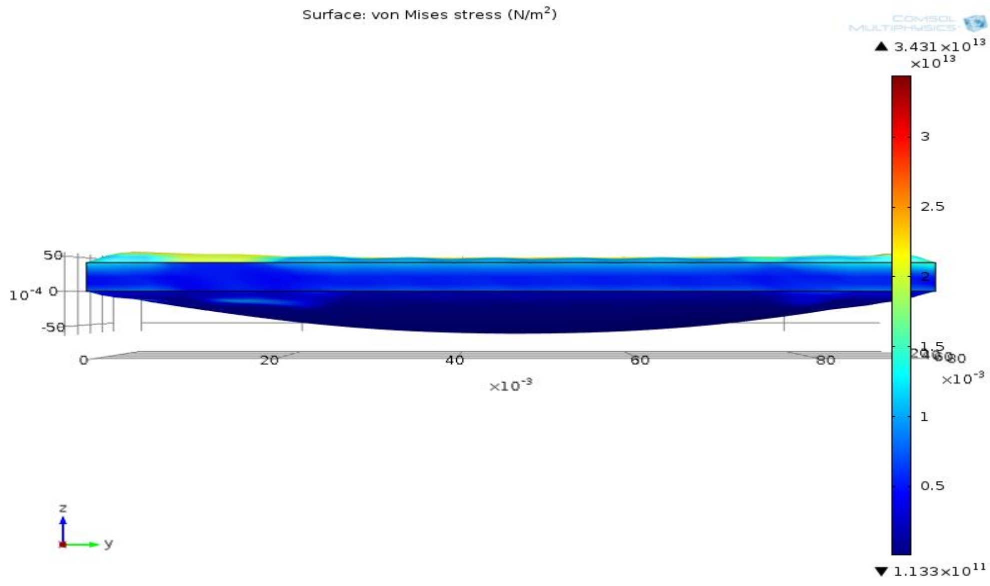


**Fig.20 VON MISES thermomechanical stress curve from the simulation under COMSOL multiphysics$\varepsilon_v = 18$**

The figures Fig.19, Fig.20, present the behavior of the VON MISES stresses of the cylinder head after simulation under COMSOL.

The simulation of a subroutine under MATLAB presents the following thermomechanical constraints:

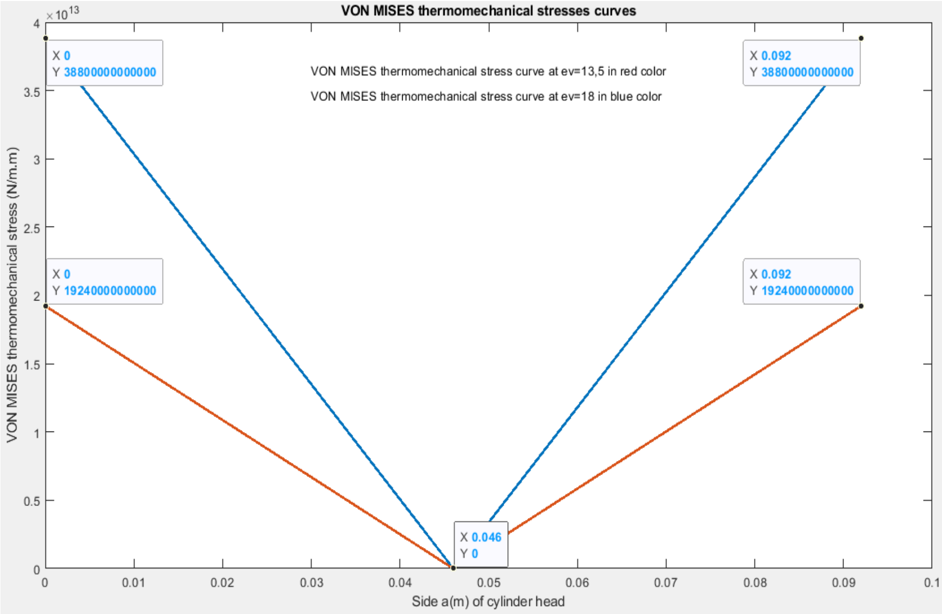


**Fig.21 VON MISES thermomechanical stress curves from MATLAB**

The simulation of a subroutine under MATLAB presents the following thermomechanical damage parameters:

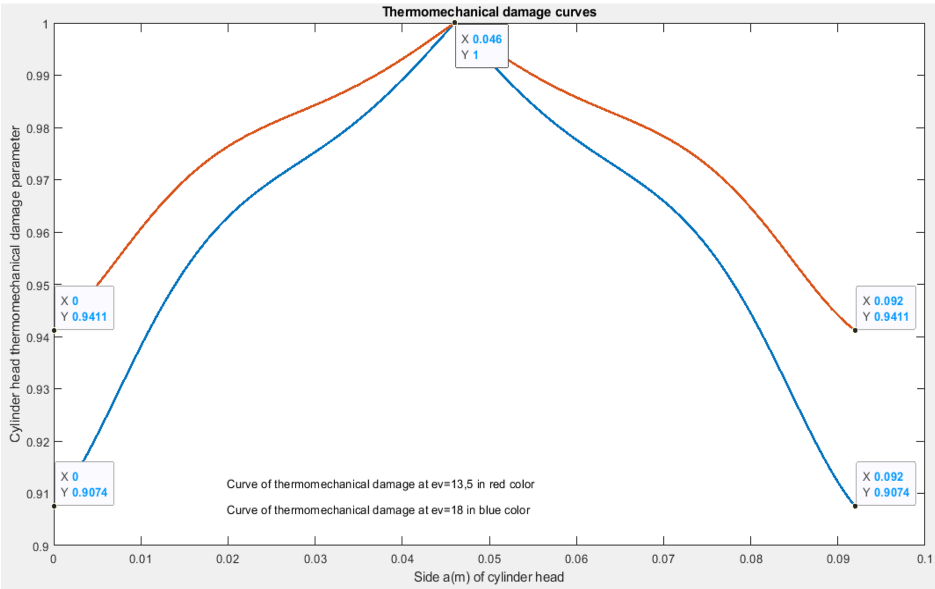


**Fig.22 Curves of thermomechanical damage from MATLAB**

It is noted that the curves of thermomechanical damage are identical to those of mechanical damage. So the conclusions are the same in this case.

The figures Fig.21, Fig.22, show the behavior of VON MISES thermomechanical stressses of the cylinder head after compilation under MATLAB.

## 4. Conclusions

In sum, the improvement in the energy efficiency of the engine with variable compression ratio demonstrated in several scientific researches presents a reverse on the damage which turns out to be high. Both on a purely mechanical level and on a thermomechanical level, the variability of the compression ratio is an obvious negative factor on the damage parameter, this through the study of our cylinder head. So this being so, several perspectives of all kinds in terms of conceptual modeling of the engine with variable compression ratio must be integrated in order to have not only energy efficiency but also resilience to increasingly significant damage.

**List of Abbreviations**

MATLAB: Matrix Laboratory

P :Combustion pressure

h : Cylinder head thickness

b : Cylinder head side

$\rho_0$ : Cylinder head density

$c_v$ : Specific heat capacity at constant volume of the cylinder head

$K_0$ : Cylinder head thermal conductivity

$t$ : Thermal conduction time of the cylinder head

$w$ : Distorsion of the cylinder head

$\varepsilon_v$ : Cylinder head compression ratio

$D$ : Bending stiffness of the cylinder head

$E$ : Young's modulus of the cylinder head

$\sigma$ : Von Mises stress

$\varepsilon$ : Cylinder head deformation

$M$ : Cylinder head bending moment

$T$ : Cylinder head shear force

$d$ : Cylinder head damage

**Declarations**

I declare that the information on my research article that I communicate in this declaration of interests is accurate and complete. I undertake to update them in the event of any modification that substantially affects them and, in any case, at least once a year

**Availability of Data and Materials**

Date and materials are available

**Competing Interests**

In our work we have no competitors i.e. no competing interests

**Funding**

In our work we received no funding

**Authors' Contributions**

The contributions of the authors are solely and purely intellectual.

All authors have read and approved the manuscript.

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