**Análisis numérico térmico de la eficiencia de sellado**

**a una junta de motor fabricada por CRS de ¼ dureza**

**con un recubrimiento de nitrilo en ambos lados**

**Thermal numerical analysis of sealing efficiency**

**to an engine gasket manufactured by CRS of ¼ hardness**

**with a nitrile coating on both sides**

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**Resumen**

Las juntas de cabeza de acero de múltiples capas son componentes de sellado pasivo importantes que existen en los motores de combustión interna y son cruciales para el rendimiento adecuado del motor. En este trabajo se propone analizar la junta de sellado con materiales compuestos (metal con recubrimiento) para garantizar la eficiencia. Los resultados de este trabajo servirán para realizar los análisis paramétricos de la fuerza de pretensado de los pernos entre el ensamblaje en frío y considerarse como una referencia de diseño para el motor de automóvil. La idea principal de este análisis numérico, es introducir el elemento de pretensión en la simulación del conjunto atornillado con los otros componentes. En comparación con el método tradicional, el elemento de pretensión tiene muchas ventajas sobre el método para controlar el aumento y la disminución de la temperatura. Asimismo, se corrobora por medio de una evaluación experimental del sistema que se está analizando numéricamente. Además, se puede concluir de manera general que la evaluación numérica es muy cercana a la realidad.

**Palabras clave:** Junta, sellado, evaluación numérica, contacto, esfuerzo.

**Abstract**

Gaskets are important passive sealing components found in internal combustion engines and crucial to proper engine performance. In this work, it is proposed to analyze the sealing gasket with composite materials (metal with coating) to guarantee efficiency. The results of this work will serve to carry out the parametric analysis of the prestressing force of the bolts between the cold assembly and be considered as a design reference for the automobile engine. The main idea of ​​this numerical analysis is to introduce the pretension element in the simulation of the bolted assembly with the other components. Compared with the traditional method, the pretension element has many advantages over the method to control the temperature rise and fall. Likewise, it is corroborated through an experimental evaluation of the system that is being analyzed numerically. In addition, it can be concluded in a general way that the numerical evaluation is very close to reality.

**Keywords;** Sealing, gasket, numerical evaluation, Contact, Stress.

# Introduction

The internal combustion engine gained importance towards the end of the XIX century [1], due to its characteristic to potential the maximum performance limit. In addition to the fact, that this type of motor is capable of exchanging the heat it produces with the outside environment, it can be adapted to a wide range of heat sources for its operation. Being an internal combustion engine it is possible to control and efficiently reduce combustion emissions. However, the working fluid is gaseous, which causes operational difficulties. In practice, it has been seen that the viable working fluids are Hydrogen and Helium (due to their excellent thermodynamic properties) [2]. The development of technology, research, and creativity of the human being in the last century have provided the basis for the optimization of this type of engine, which does add to the increase in the knowledge of fuels, and this provides a substantive advance when are used for transport. The early start was founded by; Eugenio Barsanti and Felice Matteucci [3], Alphonse Beau de Rochas [4], Nicolaus Otto [5], Rudolf Diesel [6] among others. Nonetheless, the development of fuels has had a great impact on the development and evolution of the engine. For example, during World War I, fuels with better antiknock properties were developed on a large scale [7]. On the other hand, during the past three decades, it has sought to improve engine performance, control polluting emissions, and reduce fuel consumption. Internal combustion engines are a major source of noise (exhaust system, intake system, the fan used for engine cooling, and the engine cylinder head, to mention some examples). Noise can be generated by the internal combustion process [8-9]. The internal combustion engine has improved a lot since its beginning, the performance of engines has improved from a 10% efficiency that reached the first engines, up to 35-40% nowadays. Additionally, with the application of new technologies, improvements in fuels, materials, etc. have permitted to achieve great power [10-11]. The purpose in the evolution of internal combustion engines is to optimize their operation, which is possible by improving each of its systems. The sealing of the combustion chamber is an important proposal which could be address by the development of new devices.

Currently, in the Automotive Industry there is a great variety of approaches to analyze and evaluate all types of components, so numerical analysis (Finite Element Method) is very useful [12-15]. Vast resources have been invested in the design and manufacture of engine head gaskets, where one of the most viable options is engine head gaskets made of multilayer steel (MLS). These are important passive sealing components that exist in almost all internal combustion engines and are crucial for a proper engine performance [16]. Regarding the development of gaskets for components, they are the oldest method devised produced by mankind to guarantee the water sealing by that is tightness hermeticity in equipment or facilities that work with fluids [17]. Both the Sumerians and Egyptians implemented a kind of twisted linen braid, which they covered with animal fat. This was placed in the hydraulic works to try to seal the water leaks [18]. Later in history, a great diversity of materials has been used to make seal, as they are; tow, Iron, Aluminum, bronze, Copper, sulfur powder and water to form a solid seal, Iron sulfate, pieces of rope, graphite, leather, rubber, asphalt, oil, asbestos, graphite, coal, etc. [19-22]. Today, engine head gaskets are made from a wide variety of materials including paper, rubber, silicone, metal, cork, neoprene, nitrile rubber, fiberglass, and plastic polymers [23]. Multi-Layer Steel (MLS) gaskets play an essential role in today's sealing industry for internal combustion engines. MLS type gaskets consist of multiple layers of metal (Figure 1a) [24] and contains various sealing elements. The combustion seal is the one that seals the periphery of the upper part of the monoblock cylinder with the assistance of the ribbed seals, which seal the antifreeze fluid and oil passages (Figure 1b) [25].



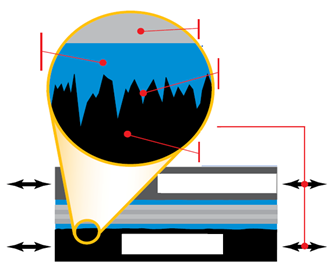
Top layer

Rivet

Middle layer

Bottom layer

a)



*FKM* or *NBR*

covering

seals rough surfaces

Steel laminate

Superficial finish; 0.0007”

Sliding surfaces

Superficial finish

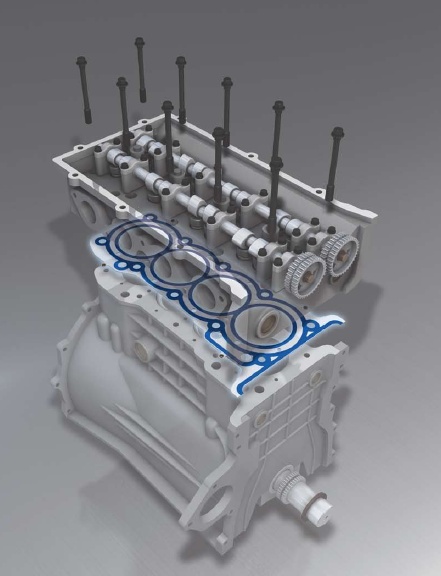
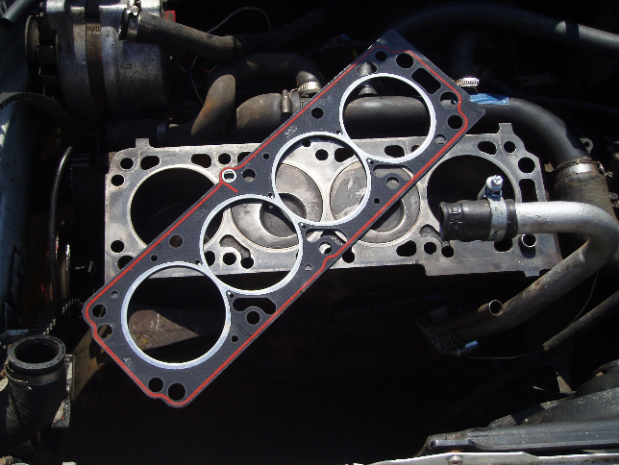
Cylinder head

Engine block

b)

**Figure 1.** Gasket construction. a) Multi-Layer Steel gasket. b) Micro-sealing

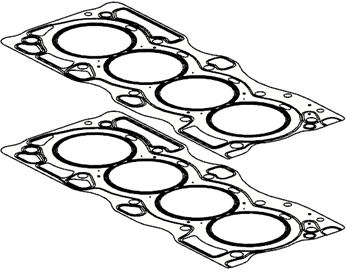
Now a day, Engineers rely more on numerical analysis studies through the Finite Element Method to improve the design of engine components and reduce the total production time of automobile components [26-27]. Finite Element Analysis is a powerful tool used by Engineers and Designers to determine how a part or assembly performs, when subjected to various conditions. Some of the parameters that can be determined are stresses, strains, displacements and thermal expansions [28]. This research is about the efficiency of an engine gasket sealing and the stress-strain behavior of a cylinder head, applying contact theory, which are analyzed under cold starting conditions. The results of this work will be used to carry out the parametric analyzes of pre-stressing forces of the bolts between the cold assembly to be considered as a design reference for the automobile engine. Likewise, the study will focus on the engine head gasket and its interaction with the block and the head or cylinder under normal working conditions. As the engine block is the largest part of the system, the cylinders and pistons are installed there. Also, the connecting studs with the cylinder head or engine gasket are installed and the lubrication and cooling circuits pass. The materials used in block must be able to resist high temperatures, since the gas expansion and exhaust process is carried out here, it is generally built in Iron with Aluminum alloys (Figure 2) [18-21].



**Figure 2.** Head gasket in a combustion engine

**2. Methodology and development**

Gaskets for engines are designed, manufactured and evaluated in a very unique way, as each type of engine requires a specific and unique head gasket design. The head gasket must maintain the seal around the combustion chamber at maximum operating temperature and pressure. The gasket should be sealed against air, coolants, combustion and engine oil, considering the respective maximum operating temperatures and pressure (Figure 3).The model of the elbow was develop through computerized axial tomography. A computer program called Simpleware ScanIP® was apply to carry out the construction of the elbow model (Figure 1). This program offers the implementation of 3D models using DICOM (Digital Imaging and Communication On Medicine) images. Which generates STL files offering a wide selection of computational tools to observe images or generate 3D files. The materials used for the manufacture of the engine head gasket must cover thermal considerations and should be able to endure chemically conditions derived from combustion products. As well as, the various chemical products (coolants and oils used in the engine) [16]. When assembled, the head gasket becomes an important part of the overall engine structure, supporting the cylinder head along with its operating components [29]. To perform the numerical analysis of the gasket, the cover type and motor model were considered. Which were simplified, eliminating radius and curves, to help the convergence in the simulation (Figure 4).



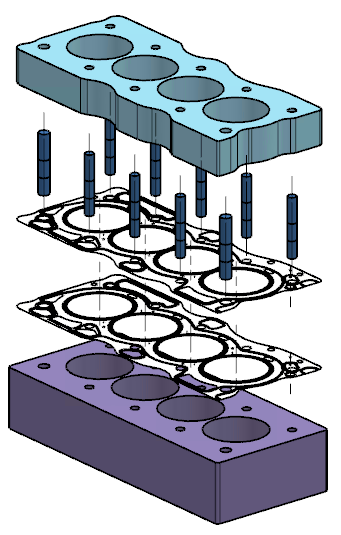
**Top layer**

Two layers of *NBR* 0.0254 mm (0.001”) and at the middle a *CRS* ¼ hard 0.2032 mm (0.008”)

**Bottom layer**

Two layers of *NBR* 0.0254 mm (0.001”) and at the middle a *CRS* ¼ hard 0.2032 mm (0.008”)

**Figure 4.** 2.5 L MLS gasket components



Motor´s cover

Clamping bolts

Top layer

Bottom layer

Monoblock

**Figure 3.** General representation of the gasket with motor´s cover andmonoblock

MLS type engine gasket is widely adopted due to its good compression recovery performance, high temperature resistance and small bolt tightening force. The typical structure of the MLS gasket generally contains the upper gasket and the lower gasket [30]. Each of these gaskets (upper and lower) are configured as if it were a sandwich with two layers of NBR on each surface and in the center a sheet of CRS ¼ hard (Figure 4). The function of the upper and lower layers is to seal the motor head, where the main ribbed are distributed. In addition, to adjusting the distribution of the pre-tightening force produced by the bolt in the motor head, due to the high working pressure, high service temperature, low pre-tightening force and small sealing areas, with severe thermal load, the varied bead is designed to implement reliable sealing in any operating condition [30]. As the first stage of the numerical analysis, solid models were used for the screws, cover and motor head. Likewise, layer models for the gaskets (lower and upper), eliminating all other engine components, with which it is possible to decrease the analysis time and reduce the computational resource. In addition, a structural analysis with a static principle is considered to determine the stresses and strains acting into the gasket. However, the elasto-plastic properties of the gasket are applied, in case the load causes the yielding of the material.

**3. Model generation and initial peripheral stages**

Firstly, it is stipulated that the numerical simulation will be developed in a structural way and generating a 3D geometry (considering 6 degrees of freedom (UX, UY, UZ, Rot x, Rot y, Rot z)). A high order tetrahedral shell element (Solid 186, 20 nodes) is applied to discretize the gasket [30-32]. While the monoblock and the engine cover are considered as rigid bodies, applying contact theory, which will allow less computational time and concentrate the study on the head gasket. The size of the elements must be conforming to the geometric characteristics of the work piece and the gradients of the process variables for each step of the manufacturing process [30]. For this case, a tetrahedral mesh of 4 mm elements was considered with 161 032 nodes and 91 703 elements (Figure 5).

**4. Mechanical properties of the materials to be used**

In Figure 4, the main parts of the MLS gasket are shown, as well as, the type of material assigned for each part [33]. The two components that make up the gasket are made of ¼ hardness CRS, with a nitrile coating on both sides (NBR), with which micro-sealing is guaranteed. Table 1 shows in a general way the elastic mechanical properties of the gasket that were used for this type of analysis. However, to carry out the most complete numerical evaluation and verify that no significant permanent deformations are produced into the gasket, the properties of the plastic zone of both materials (NBR75 and CRS ¼ hard) are introduced. This information is entered in table 2. For the NBR75 material it is specified as a non-rigid (ductile) rubber, while for CRS ¼ hard (as it is a steel), initially the yield stress is stipulated and then the plastic working area of the component is delimited (Figure 6).



**Figure 5.** Gasket layer discretization

**Table 1.-** Basic elastic properties for the gasket components

|  |  |  |  |
| --- | --- | --- | --- |
| **Gasket layer** | **Material** | **Thickness (mm)** | **Young´s modulus** |
| Top | NBR75 | 0.0254 | 5.8 MPa |
| Middle | CRS ¼ Hard | 0.2032 | 190 GPa |
| Bottom | NBR75 | 0.0254 | 5.8 MPa |

**Table 2.-** Materials stress-strain data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **NBR75** | | **CRS ¼ hard** | |
| **No.** | **Strain (mm x 10-1)** | **Stress (MPa)** | **Plastic strain (in x 10-1)** | **Stress (psi)** |
| 1 | 0.001171 | 0.034477 | 0 | 50555 |
| 2 | 0.003122 | 0.070269 | 0.0004 | 60198 |
| 3 | 0.004782 | 0.1064 | 0.0009 | 70047 |
| 4 | 0.006343 | 0.1434 | 0.0013 | 75175 |
| 5 | 0.008002 | 0.18182 | 0.0017 | 80100 |
| 6 | 0.009954 | 0.22127 | 0.0023 | 86051 |
| 7 | 0.01132 | 0.26118 | 0.0033 | 91793 |
| 8 | 0.013077 | 0.29914 | 0.0043 | 95189 |
| 9 | 0.014638 | 0.3386 | 0.0053 | 97121 |
| 10 | 0.016395 | 0.37828 | 0.0063 | 98050 |
| 11 | 0.018347 | 0.41841 | 0.0074 | 98809 |
| 12 | 0.020299 | 0.45781 | 0.0084 | 99194 |
| 13 | 0.022055 | 0.49617 | 0.0093 | 99215 |
| 14 | 0.024007 | 0.53345 |  |  |

0 0.05 0.1 0.15

Strain (mm x 10-1)

Stress (MPa)

2.5

2.0

1.5

1.0

0.5

0.0

a)

Coefficent of termal expansión; 0.00023

Reference temperature; 22 oC

Material constant C 10; 8.0953 x 105 Pa

Material constant C 01; 3.8713 x 105 Pa

Incompressible parameter D1; 1.5448 x 108 Pa-1

0 0.002 0.004 0.006 0.008 0.01

Plastic strain (in x 10-1)

Stress (x 105 psi)

1.0

0.8

0.7

0.6

0.5

Density; 0.2836 lb-in-3

Coefficient of termal expansión; 6.666 x 10-6 R-1

Poisson´s ratio; 0.3

Young´s modulus; 2.05 x 105 MPa

Shear modulus; 1.1436 x 107 psi

Bulk modulus; 2.4777 x 107 psi

Tensile and compressive yield strength; 90000 psi

Tensile ultimate strength; 99215 psi

b)

**Figure 6.** 2.5 L MLS material characteristics. a) NBR75 stress-strain graph and supplementary data. b) CRS ¼ hard stress-strain graph and supplementary data.

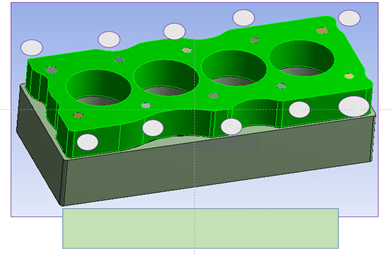
The simulated numerical behavior of the motor head gasket is considered to be elasto-plastic (represented by a bilinear behavior with kinematic hardening) [34]. The representation of the gasket materials is carried out by means of coatings, for which the modeling solution is applied in layers (Figure 6) [35-36]. The motor head, monoblock and the screws are rigid according to contact theory, so it is only necessary to apply the Young's modulus into the numerical system for each component (Table 3). With this, the numerical analysis focuses on the behavior of the head gasket. The behavior of the system is expected to be linear-elastic, however, the conditions exist to obtain elastic-plastic effects, if the application of external agents produces them. Due to the price or weight advantage of non-metals (polymers, woods, composites, etc.) over metals, non-metals are replacing metals for a variety of applications, which have a non-linear load for the characteristics of response, even under moderate loading conditions [35].

**Table 3.** Mechanical properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Material** | **Young´s modulus** | **Poisson ratio** |
| Engine head | Aluminum | 72.4 GPa | 0.3 |
| Monoblock | Gray iron | 116 GPa | 0.3 |
| Screws | Carbon steel 45 | 210 GPa | 0.29 |

**5. Boundary conditions and application of the external agent**

The boundary conditions applied to the motor head gasket sealing system include the displacement limit condition, the contact limit condition and the load limit condition [34]. With respect to the conditions of the displacement limit and according to the actual mounting conditions, six degrees are restricted in all directions (3 DOF of translation of X, Y and Z. As well as, the 3 DOF of rotation in XY, YZ and XZ planes) on the lower surface of the engine block (Figure 7) [34]. Correspondingly, for the contact boundary condition it is assumed that, at a certain scale, the contact surfaces between the cylinder head, the bolts and the gasket could not be completely flat. During assembly, intermetallic contact is produced at the rough edges across the surfaces. Initially, the cylinder head gasket goes through an elasto-plastic deformation process until the full contact force is supported. The size of the region of the plastically deformed gasket is directly proportional to the contact pressure and inversely proportional to the hardness of the material [34]. Generally speaking, penalty methods such as Lagrange multiplier methods and augmented Lagrangian method are widely used in numerical simulations by the Finite Element Method applying mechanical contact. However, penalty methods suffer from a poor conditioning that worsens as penalty values increase. The Lagrange multiplier method introduces additional unknowns and the resulting equation system is not necessarily positive-definite. Augmented Lagrangian method combines the penalty methods and the Lagrange multiplier methods and inherits the advantages of both methods [37]. The main benefit of the augmented Lagrange method for the contact problem is that it provides the robustness and stability of the penalty method. It is a simple procedure that does not involve additional equations for the discrete system. To accurately simulate the contact behavior between cylinder head and gasket under various engine operating conditions, the augmented Lagrangian method is adopted in Finite Element Method analysis [38]. The largest percentage of the load applied into the engine is the mounting load. This mainly refers to the pre-stressed condition of the bolts, which play an important sealing role in preventing gas escaping from the internal part of the engine. In this sense, to avoid insufficient gasket sealing, the bolts are pre-stressed into the range of 28-80 kN. Furthermore, the displacements of the nodes at the lower part of the block are considered fixed, to avoid rigid body movement (Figure 8) [38]. The initial effects that occur into the gasket depends directly on the tightening of the screws to close the motor, which is responsible to achieve the perfect seal into the system. Therefore, a force of 80 kN was applied during the tightening for each of the screws in the monoblock assembly. In the specific case of the system to be analyzed, a total of 10 screws are used to tighten the gasket. Consequently, the total force exercised in the engine and gasket system is 800 kN.



9

5

1

4

8

7

3

2

6

10

1 to 10 bolt tightening sequence

Individual tightening magnitude of 80 kN

**Figure 8.-** Engine head bolt tightening sequence

Refrigerant

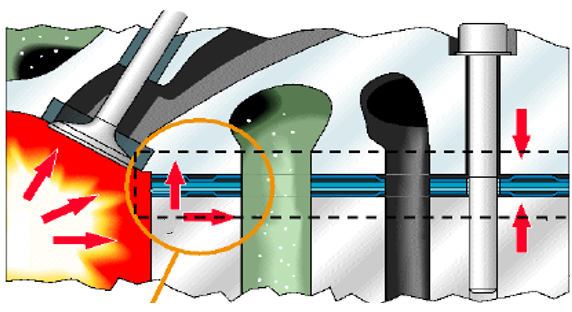
P = +3 bar

T = 30 a 125 °C

Oil;

Cold pressure; 10-12 bar,

Temperature; 30 a 120 °C



Bolt applied load

80 kN

Combustion chamber;

Pressure; +160 bar,

Temperature; 200 a 300 °C

Movement and oscillation

Covert

*MLS*

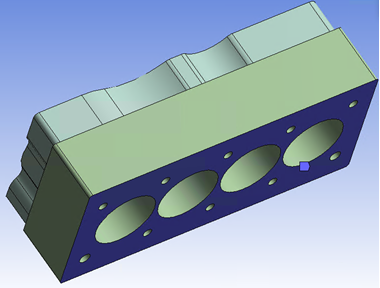
Monoblock

*P* and *T*

*s*

*F* y s

**Figure 9.** Installation conditions and functional **specifications of head gaskets**



*Ux = Uy = Uz = 0*

*Rotx = Roty = Rotz = 0*

**Figure 7.** Boundary conditions into the system

The combustion process has a particular behavior, which depends on maximum pressure, temperature, gasket and monoblock materials (bolts, force, location, etc.) and guarantee, at all times the mainly safe sealing.

# In Figure 9 and only as information, since a thermo-mechanical analysis will not be performed in this evaluation, all the requirements the engine gasket must meet are shown.

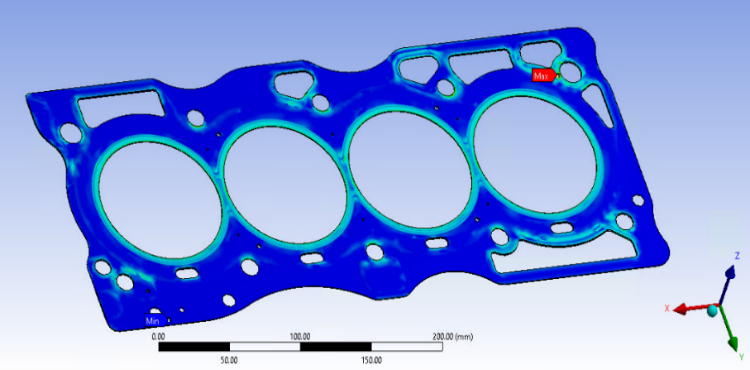
# 

**6. Model solution**

At this stage, the desired results of the analysis are defined and the solution is activated. The stresses within the cylinder head gasket are the result of external agents acting on the gasket surface (called surface forces) and forces acting on the entire volume (called body forces). Under the influence of the applied forces, the gasket will shift. The gasket is assumed to behave elastically and returns to its initial configuration when applied loads are removed. A measure of the relative elongation of the solid body is known as strain and the applied load is 80 kN [39].

**7. Results**

Basic results are presented in the manner of von Mises stresses and contact between layers.



0.018133 (MPa)

0.0161216

0.01411

0.012098

0.010086

0.00807427

0.0060624

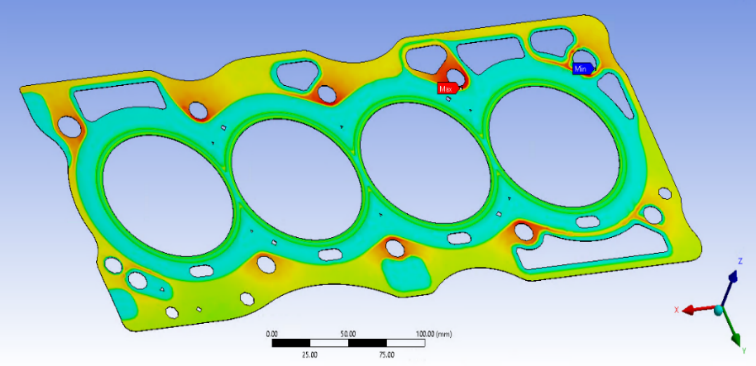
0.0040507

0.0020389

-2.7116 x10-5



**Figure 10.** von Mises stress in conjunction of the lower and superior gasket layers**specifications of head gaskets**



74.454 (MPa)

57.925

41.397

31.535

21.673

11.812

1.9501

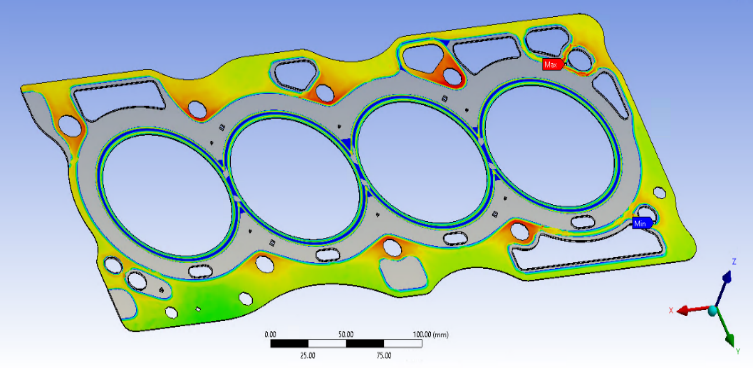
-7.9114

-17.773

-27.635



**Figure 11.** Contact effect between the top gasket layer and the covert layers**specifications of head gaskets**



85.836 (MPa)

58.576

45.703

32.83

27.358

21.887

16.415

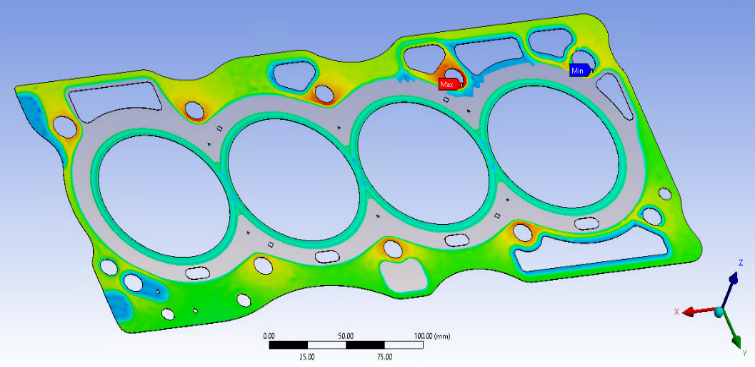
10.943

5.4717

0



**Figure 12.** Contact effect between the top gasket layer and the lower gasket layer layers**specifications of head gaskets**



70.875 (MPa)

61.306

51.736

42.167

32.598

23.028

13.459

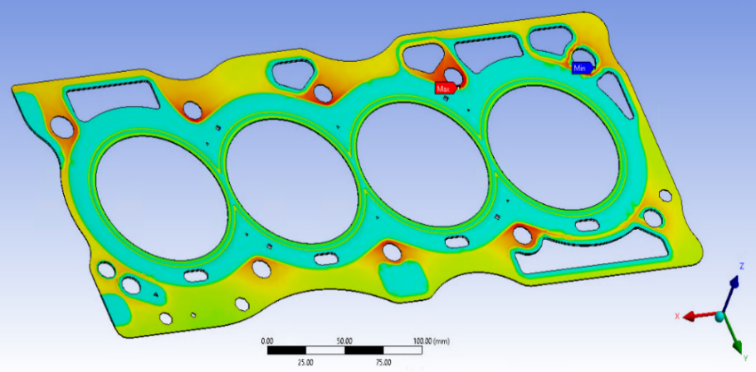
3.8895

-5.6799

-15.249



**Figure 13.** Contact effect between the lower gasket layer and the monoblock s**specifications of head gaskets**



77.62 (MPa)

59.508

41.397

31.535

21.673

11.812

1.9501

-7.9114

-17.773

-27.635

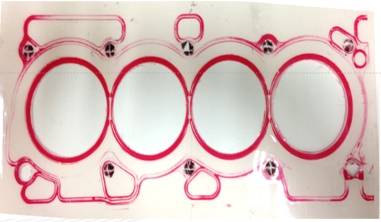
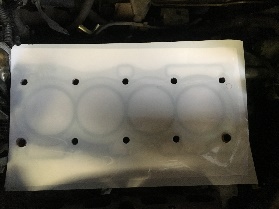
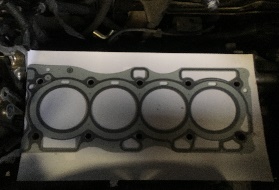
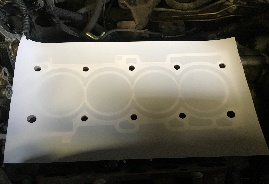


**Figure 14.** Contact effect covert-superior gasket layer and lower gasket layer-monoblock s**specifications of head gaskets**

# 7. Experimental corroboration

# For the validation of the numerical evaluation and the model development, experimental tests of the sealing pressure are carried out under the working conditions of the bolt tightening force. One of this kind of experimental tests, is the sealing of the engine by pressure developer paper (Figure 15). For this type of evaluation, the following components are needed; Contact paper, Torque-meter, Simulating plate, Screws in good condition, Head torque specification, Head gasket (different types), Shims (if applicable). The result of the experimental evaluation shows the places where there is the highest contact pressure between the head gasket, the monoblock and the head gasket with the covert. The revealing pressure paper distribution shows contours similar to those of the numerical simulation. Furthermore, a leak test is carried out in the cylinders where a pressure of 125 to 150 Psi (1.03421 MPa) is supplied into the combustion chamber (in each cylinder), if there is any leak greater than 5% it is considered that the gasket fails, in this case it was registered 145 Psi (0.99974 MPa) in each cylinder being approved for its use.

1.- Contact paper in the engine block.



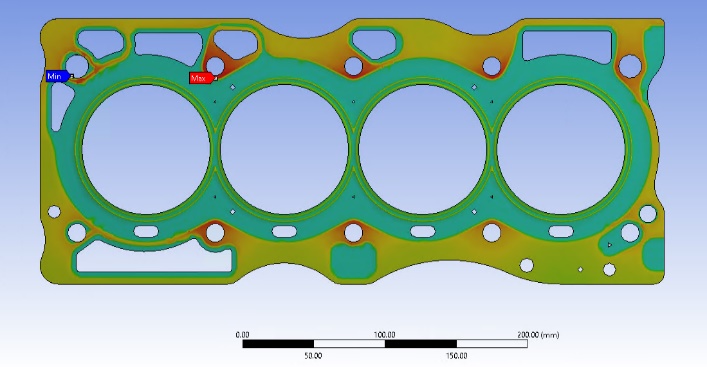
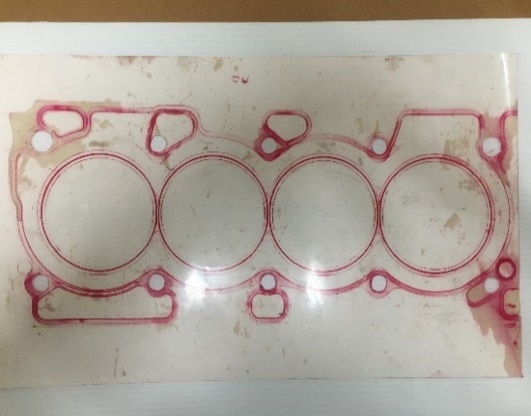
2.- Place head gasket in position.

5.- Disassemble paper and result analysis.

4.- Place screws according to the sequence recommended by the supplier and carry out the tightening sequence.

3.- Applied paper in the motor side.

**Figure 15.** Seal test sequence with pressure developer papers



**Figure 16.** Comparison of contact effect between evaluations (covert to superior gasket layer)

# 8. Conclusions

The results presented are consequence of the effect of the acting load and the contact force in its most basic form and represents an important index on the engine head gasket sealing reliability. Figure 10 shows the von Mises stresses, which show that a ductile material begins to yield at one specific location when the stress equals the elastic limit. It would indicate, that the material could fail in this zone. When a cylinder head gasket is installed between the cylinder head and the engine block, the tightening of the head bolts slightly compresses the gasket, allowing the soft material in the gasket to conform into minor surface irregularities that exist between the platform and the block. Which allows the gasket to cold seal the system, so that no coolant fluid escapes until the engine is started. A height decrease can be observed at the ribbed areas and near the combustion chamber, as well as, at the water and oil passage areas, which indicates that, due to the pressure of the screws, when mounting them into the engine, they generate a reacting force that generates the sealing through the ribbed. Contact forces is the most basic and important index on the engine head gasket sealing reliability. In Figures 11 to 14 are shown the general distribution of the stresses on the contacts in the system. The full stresses on the ribbed in the cylinder bores are greater than half the stresses of the beads in the coolant fluid bores and lubrication bores. The maximum contact stress is 74.454 MPa. It is also observed that the cylinder area has a stress of almost 50 MPa, enough to meet the factory requirement of sealing pressure. The pressures in the cylinder zone must be more than 20 MPa according to the client's requirements.

With the development of internal combustion engines and all the studies carried out on the engines, MLS type engine seals take on great relevance in their operation, having to evolve with advances in technology. The von Mises stresses are presented, in order to know if the gasket is in risk of failure at some point of the sealing process, by observing the results data it was concluded that there is no risk of failure or damage into the component. The locking of the screws generates a reaction force that produce the seal throughout the ribbed, which it is essential to produce the sealing through the entire engine system. Correspondingly, by the numerical analysis, it can be observed that the gasket shows a very localized stress field around the cap screw, which is to be expected and can be related to the concentration of stress caused by the geometry. The numerical simulation results show that the contact stresses of the ribbed around the cylinder port are greater than 50 MPa and the contact stresses of the rib media around the refrigerant holes and lubrication holes are greater than 10 MPa, which meets the customer's design sealing pressure requirement. Correspondingly, it is concluded that the gasket sealing capacity depends mainly on the pre-stressing of the bolts, which are the main source of the maximum external load on the cylinder head. At the same time, the gasket structure at the worst seal region could be improved in the early design stages by the results obtained with the numerical analysis.

The development of this type of analysis when designing an engine gasket, will result in time savings and cost reduction, in product development, compared to the Fuji film test. Moreover, it can be established a new design process methodology, CAE and validation, which could provide improve productivity, as well as, save testing and evaluating time, costs involved in gasket design and should prove better efficiency when the product is commercializes. By producing a proper sealing between all the components of the powertrain, the engine efficiency could be increase, it can be achieved an improvement of the product performance and a reduction of emissions to the atmosphere. Finally, with the results accomplished by means of the finite element analysis and comparing with those of the experimental tests carried out, it was possible to validate that in both cases there is a coincidence.

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