ALTRAN ITALIA
Mechanical engineering

PERMAS
Users' Conference
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# Design and validation of a piston pin in composite material

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# AGENDA

# Who We Are

## Altran Group - Mechanical Engineering Solution

› Mechanical design support for several product type

› Support on mechanical design in multidisciplinary project

› Virtual design & testing for time to market reduction

› Composite and advanced materials knowledge for high performance structures design

›Dedicated HW/SW computational resources

› Operating overall the European countries with core teams in Italy, Germany, Spain, UK and Netherlands.

›On/shore and off/shore resources from Europe, India, China and US

› 1000 people community working on mechanical projects

› Cross experience in several industrial markets

› Experience in the most technological applications

# What We Offer

## Solutions tailored on client needs

### PRODUCT ENGINEERING GLOBAL SUPPORT

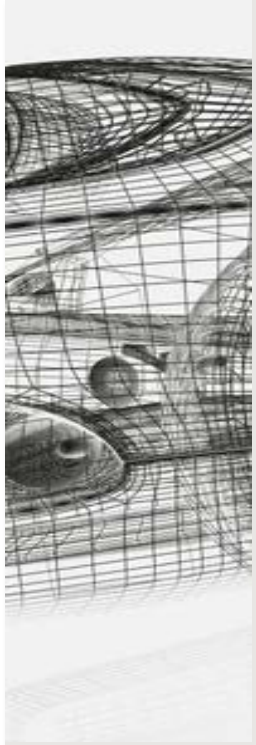
- CONCEPTUAL PRODUCT ENGINEERING
- MODEL BASE PRODUCT DESIGN
- PROTOTYPE MANUFACTURING & QUALIFICATION

*Our excellence in product design development & management*

### VIRTUAL DESIGN (CAD)

- PRELIMINARY STUDIES
- SYSTEM ENGINEERING
- 3D&2D CAD MODELING
- NEW TECHNICAL SOLUTIONS
- CONFIGURATION & PRODUCT DATA MANAGEMENT (PDM)

*Our flexible & multi-sectors design services*



### VIRTUAL VALIDATION (CAE)

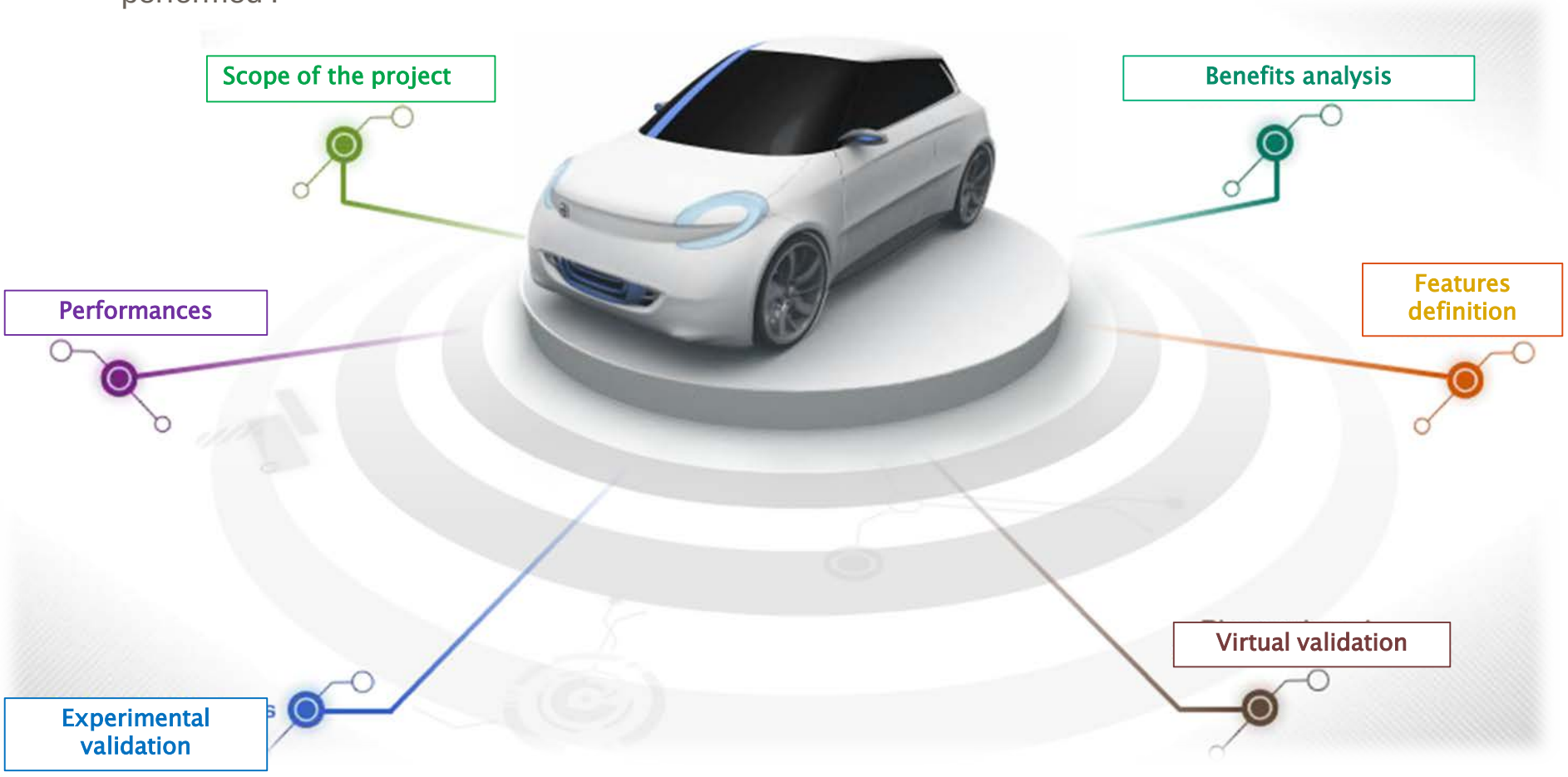
- CFD ANALYSIS
- FEM ANALYSIS
- CAE KNOW HOW DEVELOPMENT

*Our flexible & multi-sectors simulation & validation services*

# Summary

## Solutions tailored on client needs

The development of a new components for the improvement of the vehicle performance needs feasibility, functional and structural analysis.
During the development process of the multi materials piston pin, the following steps have been performed :



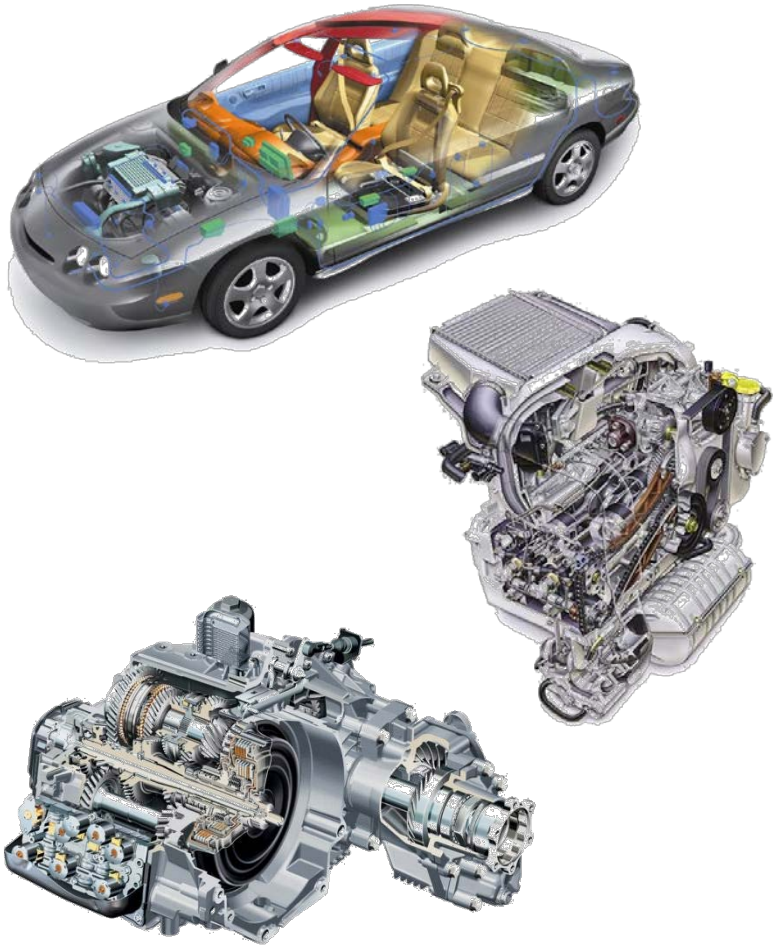
# Scope of the project

## Solutions tailored on client needs

In the last years the automotive industry is looking for innovative solutions in order to increase the performance and to reduce fuel consumption and emissions.

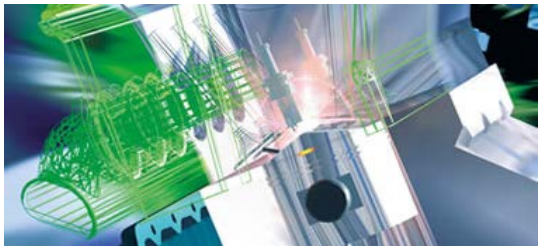
One of the key parameter is the use of composite materials in order to have lightweight components with a high structural strength.

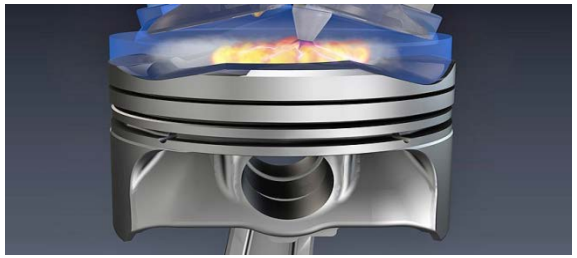
In this field of research and development, the idea of multi-material piston pin is born, the use of composite material for the piston pin permits to have high structural performance and a significant weight reduction.

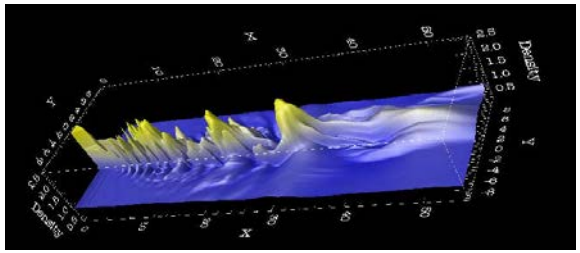


# Benefits

## Solutions tailored on client needs







WEIGHT REDUCTION

FRICTION REDUCTION

NOISE REDUCTION

### Advantages of multi-material pin

Multi-material piston pin permits a significantly reduction of the weight. Moreover the pin weight decrement generates a reduction of the inertial loads. For this reason it is possible to obtain, with a suitable redesign, also a reduction of con rod and crankshaft weight.

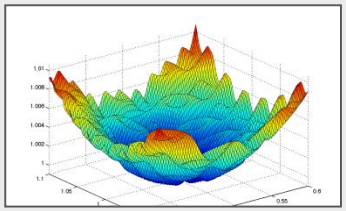
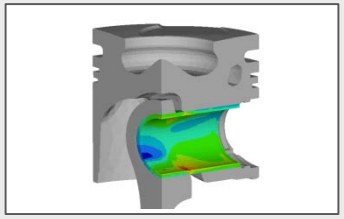
The introduction of a new piston pin design into the crank-train allows to reduce the forces of inertia. For this reason, in particular for the high engine speed, there is a relevant decrement of the forces exchanged between the piston and liner, between con rod and piston pin and between con rod and crankshaft. This load reduction generates a decrement of the engine friction.

The multi-material piston pin allows to obtain a reduction of the reciprocating masses which are the main cause of the vibrations transmitted by the engine to the chassis for common passenger vehicles and industrial ones.
Furthermore, the reduction of the exchanged forces between the piston and liner allow to reduce the noise due to the piston slap

# Design Steps

## Solutions tailored on client needs

## Performed analysis

| Research of material | Layout optimization | Virtual Validation | Bench validation | On-board validation |
|---|---|---|---|---|
| The most important composite materials available on the market were identified and analyzed in order to spot the most suitable material for the multi-material piston pin application. | Through several numerical analysis, the optimal design of the piston pin has been identified to have a optimal structural behavior for low and high temperatures | The optimized design has been validated by finite element analysis. The validation has been performed for structural behavior and for reliability point of view | The piston design has passed an experimental synthesis cycle on a engine test bench. At the end of experimental test the pin had no wear or fatigue problems | The final design of the bimetallic piston has been tested on road. During the test a decrement of vibration and of fuel consumption measured |
|  |  |  |  |  |

## Process of virtual validation of the pin



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# Material Properties

## Solutions tailored on client needs

In defining the characteristics of the plug, the following objectives have been taken into account :

### Reliability

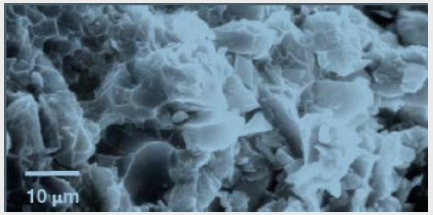
The composite material ensures an high structural behaviour and process reliability. This composite alloy is used from many years in civil and military aviation industry.

### Lightness

The composite material has a slight higher density than an aluminum alloy but a mechanical properties significantly superior.

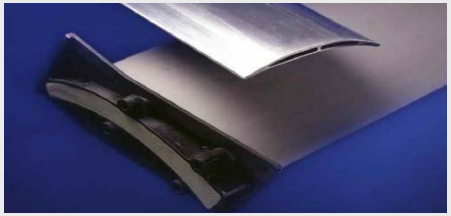
### Strength

The composite material has a mechanical properties similar to a micro-alloyed steel and it has a stiffness comparable to the cast iron. These structural properties are retained also at high temperatures.




### Price

The material is employed in the aeronautical industry and its cost is competitive even if it is higher than micro-alloyed steel. A large scale production would still permit a cost reduction.



**Features of composite material**



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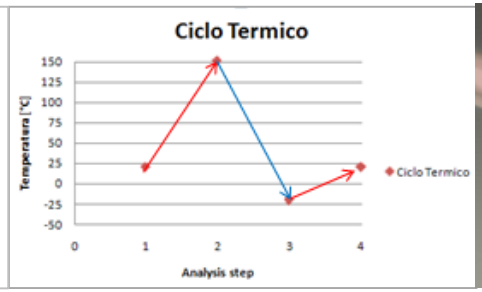
# Virtual Analysis

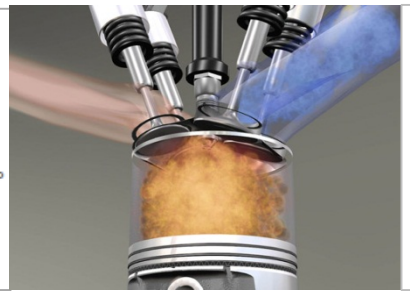
## Solutions tailored on client needs

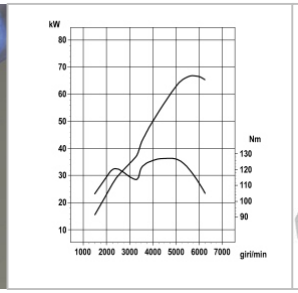
The design of the pin has been validated through a finite element analysis, in order to verify the structural behavior of the piston pin.

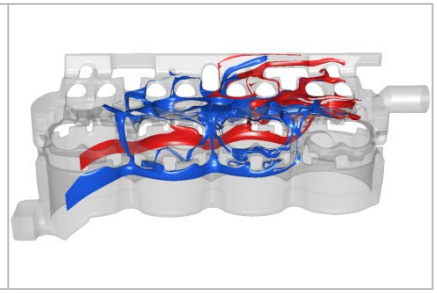
The model composed by piston pin , connecting rod and piston, has been analyzed through the following steps:

**System assembly** → **System thermal cycle** → **Pressures of combustion** → **cooling**



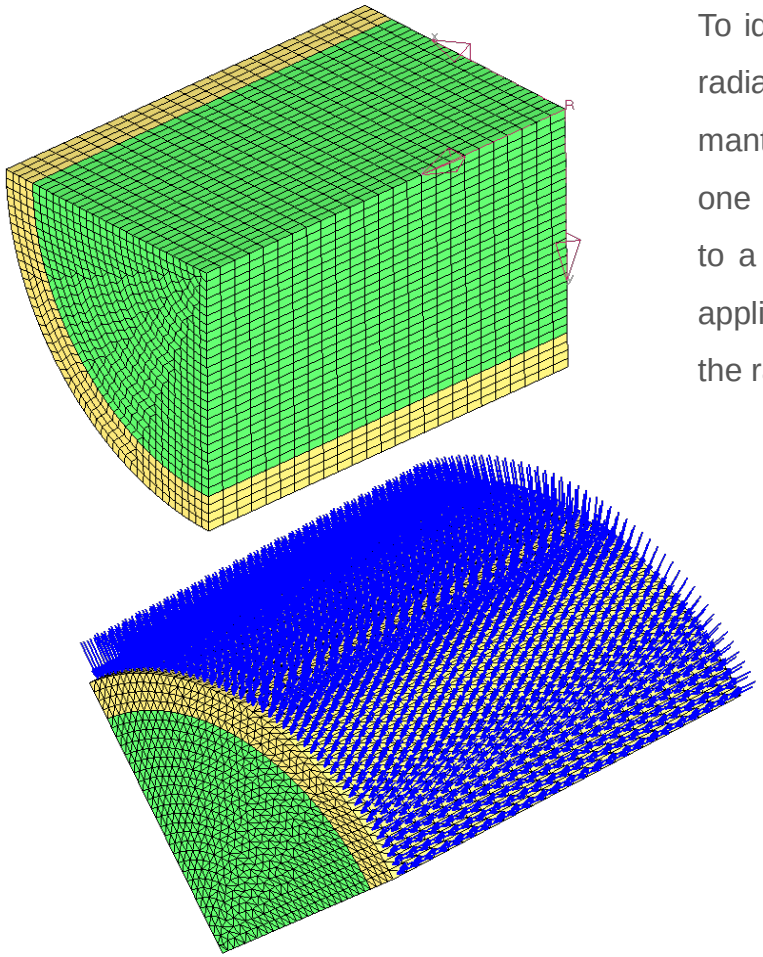


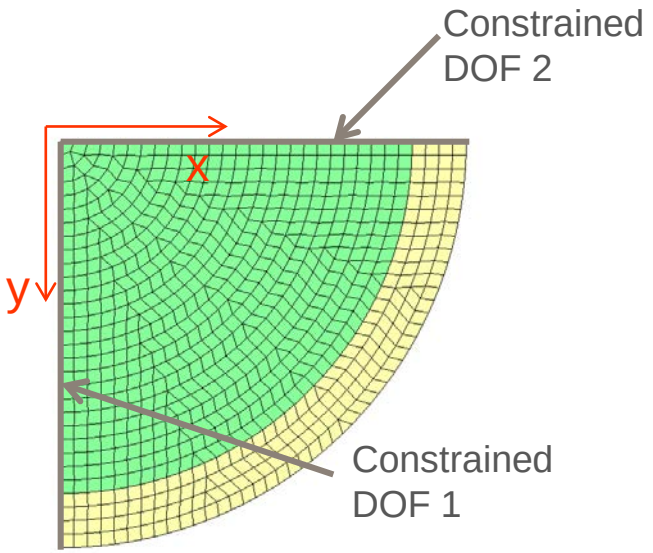
# Virtual Analysis – Bimetallic Piston Pin

## Solutions tailored on client needs

## *Radial Stiffness Analysis*



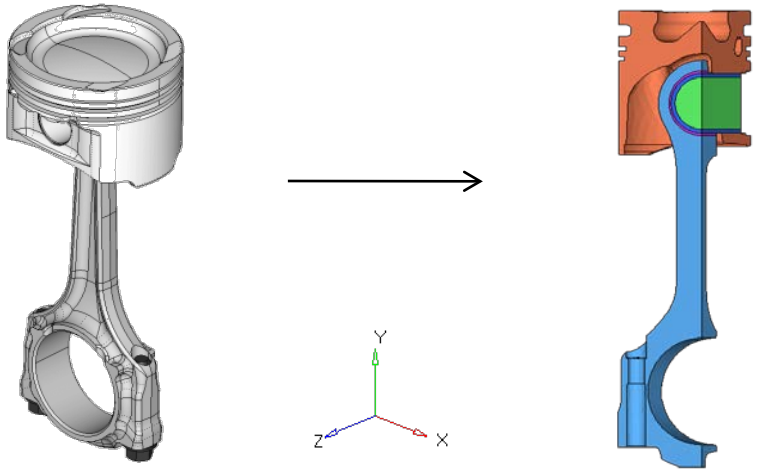
To identify the right ratio between steel and metal composite, the radial stiffness of the plug was evaluated as the thickness of the mantle varies. The analysis of radial stiffness was performed on one eighth of the plug using the symmetry. The plug was brought to a temperature of 100 ° C and a pressure of 10000 MPa was applied to the outer surface of the plug. For stiffness evaluation the radial displacement of a model node was measured.

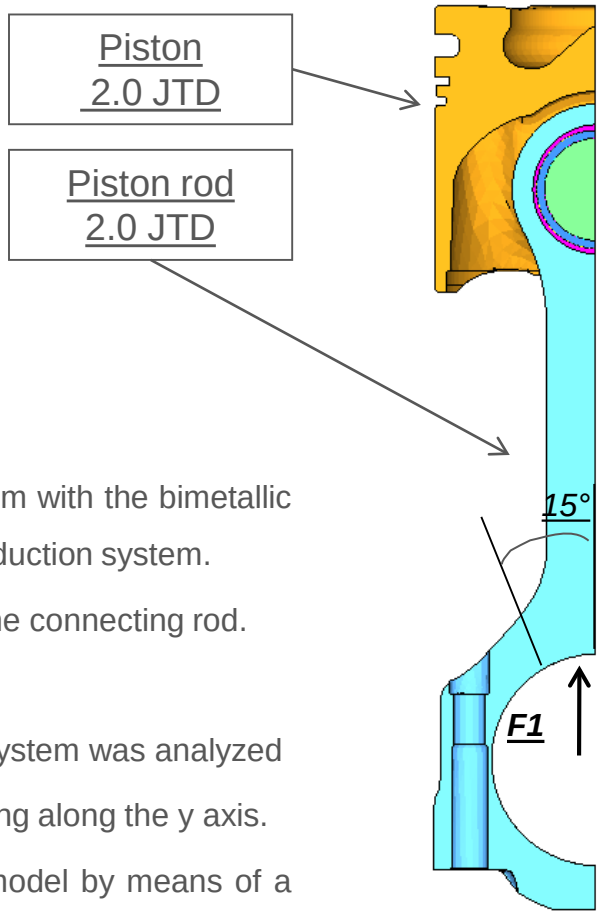


# Virtual Analysis – Bimetallic Piston Pin

## Solutions tailored on client needs

## *Complete Stiffness Analysis*




The aim of the analysis is the stiffness evaluation of the complete system with the bimetallic composite piston pin and compare it with the stiffness of the current production system.

The complete system consists of the piston, the bushings, the pin and the connecting rod.

Taking advantage of the symmetry of the system, only a quarter of the system was analyzed

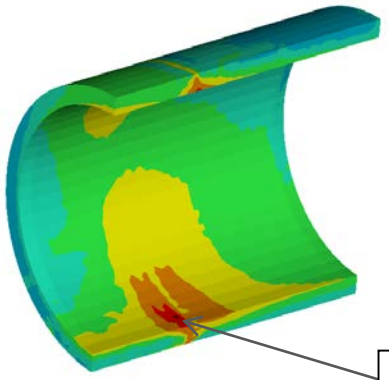
The piston crown has been constrained so as to prevent it from translating along the y axis.

The force generated by combustion has been inserted into the FEM model by means of a force F1 applied to a node connected by an element $MPC RIGID to the nodes corresponding to the pressure zone of the bearing housed in the big connecting rod eye.

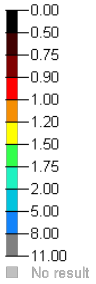
# Virtual Analysis

## Solutions tailored on client needs

## *Results: Fatigue on mantle pin*

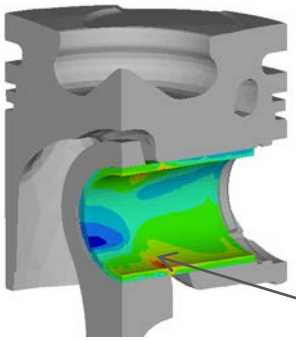


Fatigue safety factor [-]

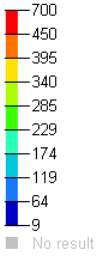



$SF_{R=cost} = 0.8$

***Step 3 – Gas Pressure***

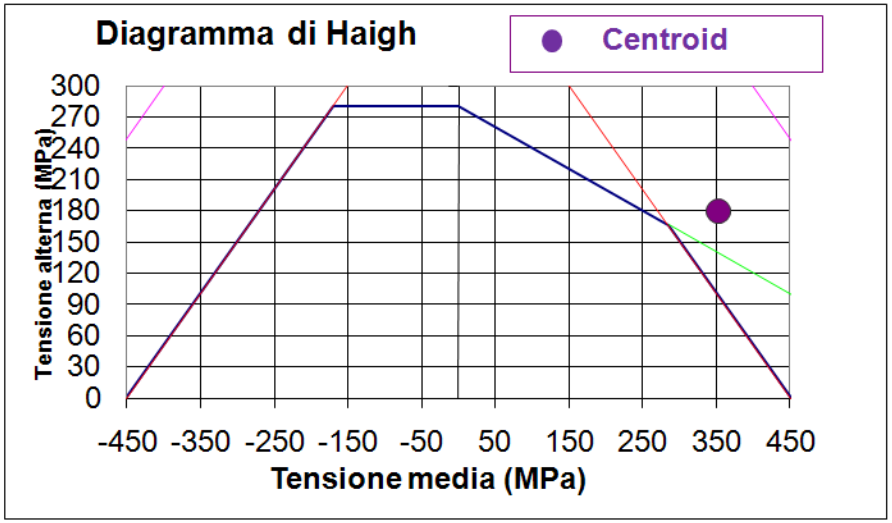


Von Mises [MPa]




$\sigma_{VM} = 159.7$ MPa

## ***DIAGRAMMA DI HAIGH***




$\sigma_{,mean} = 352.7$ Mpa

$\sigma_{alternating} = 179.5$ Mpa

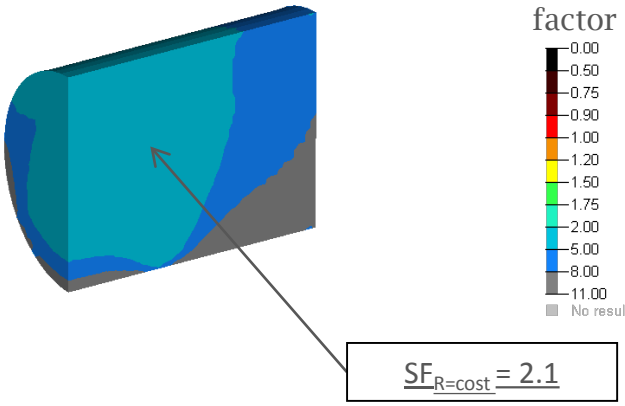
$SF_{R=Const} = 0.8$

$SF_{\sigma m=Const} = 0.5$

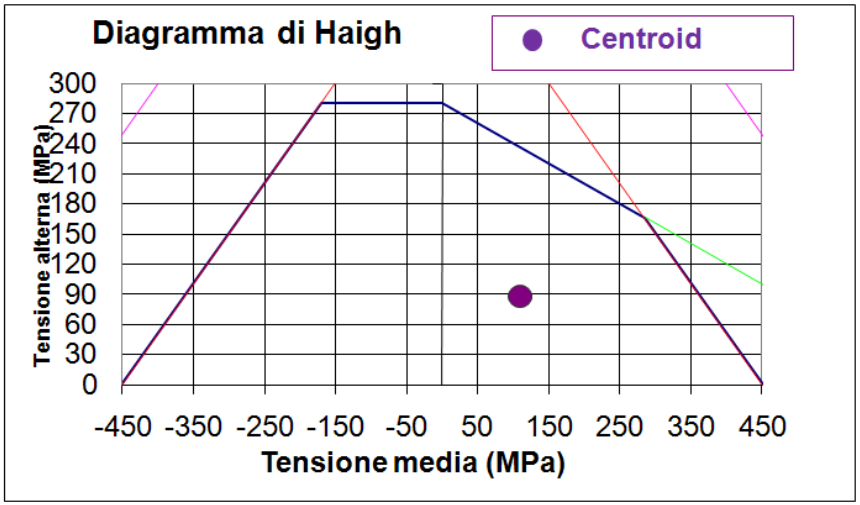
# Virtual Analysis

## Solutions tailored on client needs

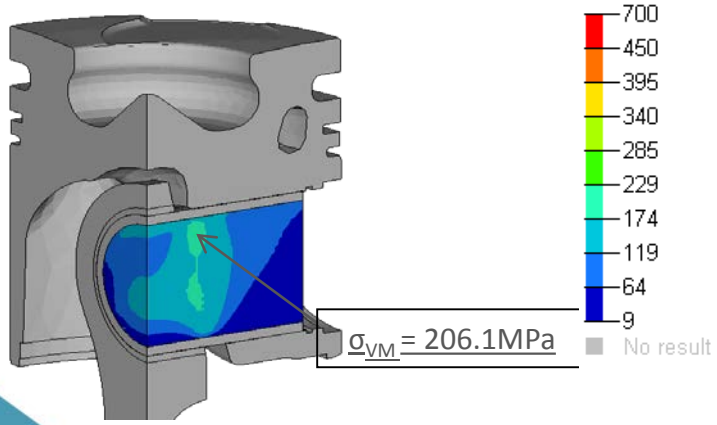
## *Results: Fatigue on inner pin*




### *DIAGRAMMA DI HAIGH*




***Step 3 – Gas Pressure***




$\sigma_{mean}$ = 109.8 Mpa

$\sigma_{alternating}$ = 87.9 Mpa

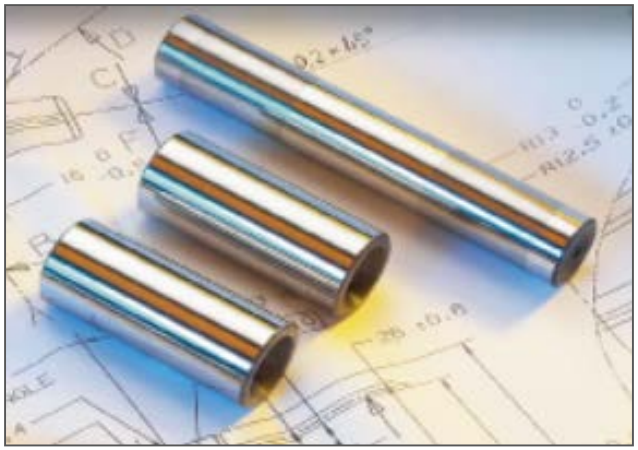
$SF_{R=Const}$ = 2.1

$SF_{\sigma m=Const}$ = 2.7

# Virtual Analysis

## Solutions tailored on client needs

In the tables below there are the stiffness variations of the bimetallic pin respect a traditional steel one, for a diesel engine of average cylinder displacement.



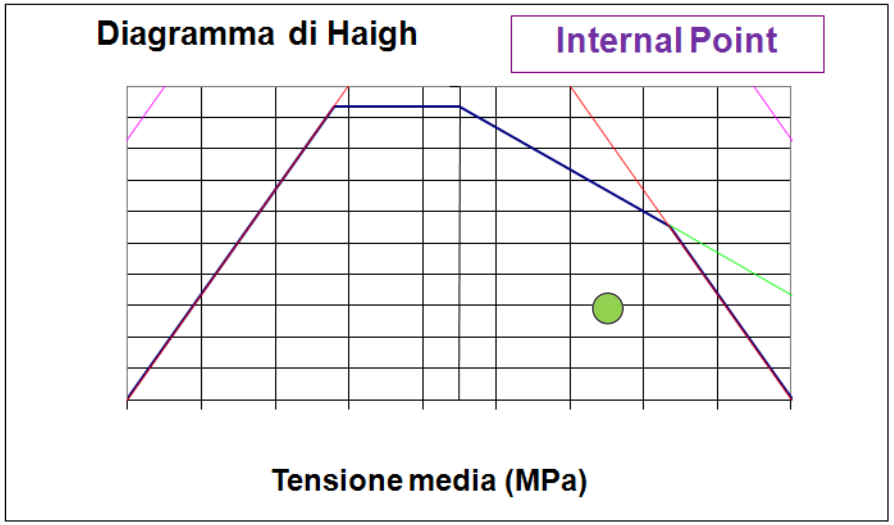
The use of composite material allows to reduce the weight of the pin and to increase the radial stiffness. The cranktrain has a slight reduction in the flexural stiffness.

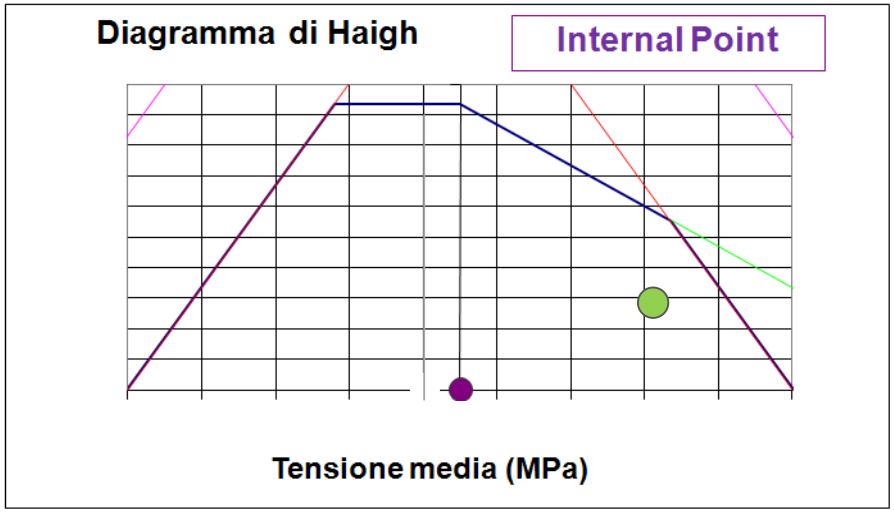
| weight | Radial stiffness |
|---|---|
| 0% | +40% |
| -10% | +30% |
| -20% | +25% |
| -30% | +15% |
| -40% | +10% |

| Temperature | weight | Bending stiffness |
|---|---|---|
| 20° | -32% | -5% |
| 100° | -32% | -8% |
| 100° | -15% | -5% |
| 100° | -8% | -2% |

# Virtual Analysis

## Solutions tailored on client needs




**Haigh diagram**

**Composite material**

**Safety Factor > 2.5**

The results obtained by the structural analysis were used to perform a fatigue analysis of steel and of composite material used for the multi-material pin

**Haigh diagram**

**Steel**

**Safety Factor > 1.4**



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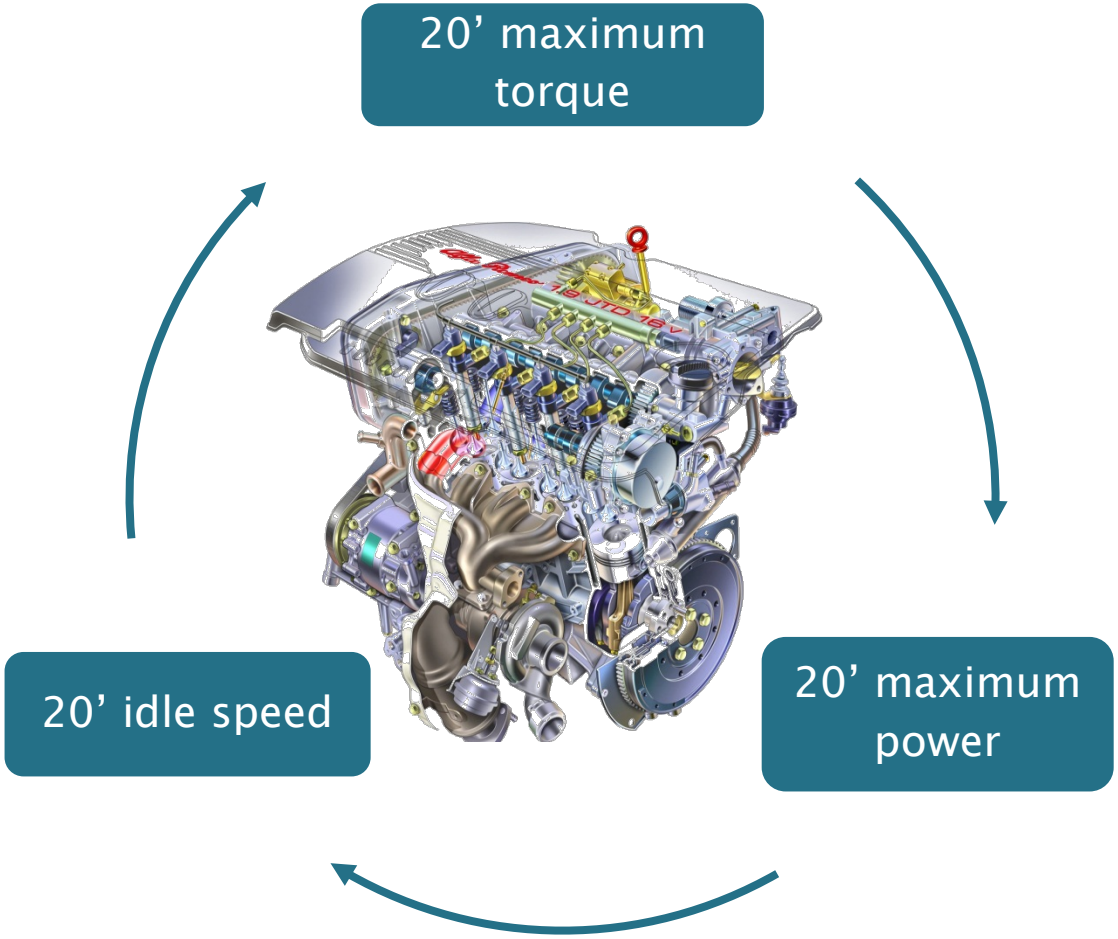
# Bench Test

## Solutions tailored on client needs

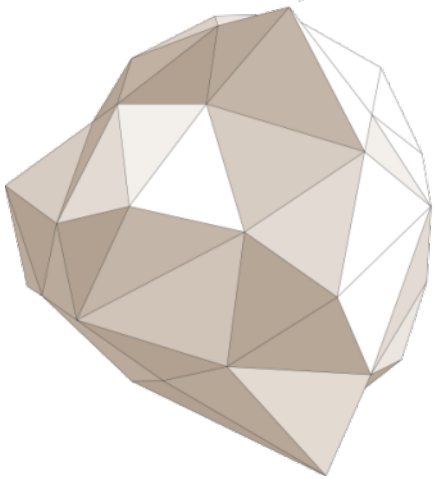



After the virtual validation, the piston pin was tested with an engine bench through the synthesis cycle shown in the figure.

The synthesis cycle had a total duration of 240 hours.

At the end of the cycle there were no structural fatigue problems or wear phenomena on the piston pin.

# INNOVATION MAKERS



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