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THEORETICAL CONSIDERATIONS ON LABORATORY MODELING OF THERMAL FATIGUE PHENOMENON

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ABSTRACT: *This paper aims to study the principles and concepts underlying the thermal fatigue modeling under laboratory conditions. The main objective of this paper is to take a decision on laboratory modeling of thermal fatigue that occurs in parts of machines constituting internal combustion engines. Thermal fatigue study under laboratory conditions lead to the thermal fatigue resistance limits for different machine parts in the composition of internal combustion engines, specific to avoid cracking of the engine by optimizing the thermal regime and proposals for new materials with high resistance to thermal fatigue.*
KEYWORDS: *thermal fatigue, modelation, cycles, fissure, model, laboratory*

INTRODUCTION

During operation, the component parts of internal combustion engines are subject to the action of cyclic variable thermal fields, producing thermal fatigue cracks. These cracks appear only after a certain number of thermal cycles. This number depends on the material and operating mode of engine parameters. With increasing number of thermal cycles the thermal fatigue grows gradually and this phenomenon is characterized by specific surface cracks in the surface layer of engine parts. This leads to an adverse change in the energy and economic indices of the engine. Study of thermal fatigue phenomenon internal combustion engines is necessary not only to reduce the raging crack, but also to avoid thermal shock in the extremely dangerous operation of engine [1], [2], [4].

This paper aims to study the principles and concepts underlying the thermal fatigue modeling under laboratory conditions. The main objective of this paper is to take a decision on laboratory modeling of thermal fatigue that occurs in parts of machines constituting internal combustion engines. Thermal fatigue study under laboratory conditions lead to the thermal fatigue resistance limits for different machine parts in the composition of internal combustion engines subject to this phenomenon, specific to avoid cracking of the engine by optimizing the thermal regime and proposals for new materials with high resistance to thermal fatigue.

Thermal fatigue research internal combustion engines, in particular the fixed and mobile machine parts of their structure is less studied both nationally, and internationally.

CRITERIA AND CONCEPTS FOR IDENTIFYING THERMAL FATIGUE

The criteria which characterize the thermal behavior of the solicitation materials cyclical variable is the thermal fatigue resistance [1], [3], [4] . This is determined and expressed as the number of thermal cycles. Thermal fatigue occurs after a large number of thermal cycles. So far, thermal fatigue tests were performed for a number of cycles of a few tens to tens of thousands of thermal cycles, [1], [3].

The concept of thermal fatigue is the subject of numerous studies, specific to various fields, [1], [3], [5]. Thus, the research conducted to date in this field and discussed various concepts that define this phenomenon, [1].

The concept Manson-Coffin defines thermal fatigue damage and destruction of materials, like an effect of thermal stress of repeated action. Once the time-varying deformations, due to purely mechanical stresses exceed certain limits, the material damage accumulation process is initializing by mechanical fatigue process that may arise under stationary and nonstationary temperature, [1].

Baladin concept defines the thermal fatigue cracking as metallic elements (specimens, components, structures, machine parts, etc.) action under varying thermal cyclic stresses, tensions arising from the change in size constrained and variable conditions of periodic temperature changes, [1]. Cracks appear after a certain number of thermal exchanges, number depending on the defining characteristics of the material and certain parameters of the test regime, testing, operation etc.

However, previous cracks, occurring in material irreversible structural changes, which directly influences the mechanical characteristics of materials constituting the metallic elements. This leads to changes more or less noticeable shapes and sizes. The first thermal fatigue cracks are difficult to detect and appear on the surface elements. Increasing the number of thermal cycles, the weighting and expansion crack is widening. It can lead to a network of cracks and their development in depth as finally there is the appearance of pierced cracks, [1].

Thermal fatigue Weronski concept defines as a process of deformation and degradation of machine parts under the influence of variabile temperature changes, [1]. In principle, it is accepted that thermal fatigue processes arising as a result of temperature changes and therefore no additional demand by external forces. Repeated cycles of heat stress (heating - cooling), initiated in car bodies, non-stationary thermal stress fields that after exceeding certain intensity, dependent on material and application conditions, involves the appearance of local cracks. These cyclical changes during temperature variations and forms cracks which eventually causes destruction of machine parts, [1].

According to the concept Dulnev-Kotov gradual damage accumulation under cyclic thermal stress action for a temperature T=const., in the circumstances of elastic-plastic cyclic deformation results in destruction of materials for a small number of cycles is called isothermal cycle fatigue life, [1]. That damage, for which, within a cycle of deformation elastic-plastic, the effect of compression (constraint) corresponds to the maximum temperature of thermal cycle, is called thermal fatigue , [1].

According to the concept Tuliakov, thermal fatigue is seen as a result of complex changes to the structure of ferrous materials and damage accumulation under cyclic deformation process thermoelastoplastic. This phenomenon depends on the type of material, the maximum cycle temperature, the range of minimum and maximum temperatures and other plastic factors deformation mechanism. Intergranular damage specific high temperatures, the large number of application cycles, l low frequencies and low temperatures corresponding transgranular damage and a small number of load cycles, [1].

According to Harvey damage concept by requiring thermal cycle fatigue names tensotermic. Among the factors that influence the behavior of the material circumstances of fatigue, ductility is important in terms of thermal fatigue. Cycles of thermal stresses generate initial cracking and subsequent cycles are characterized by their slow propagation. Thus, initial thermal fatigue cracks can become the main core of the beginning of mechanical fatigue failure, [1].

The literature has not mentioned an indicator for estimating thermal fatigue resistance of materials that is applicable under conditions of temperature, both stationary and transient [1], [6], [7]. It is however known that thermal stress generated by variable temperature fields is proportional to the thermal gradient "Δt", decreasing along with increasing thermal conductivity 'λ', [1], [6], [7].

MODELING PRINCIPLES OF THERMAL FATIGUE IN LABORATORY CONDITIONS

Thermal fatigue studies require accurate modeling of the thermal cycle regime and the state machine dimensional body subjected during operation of this phenomenon, etc.

Multitude of factors influencing the damage by thermal fatigue makes it impossible to develop a methodology to provide universal results consistent with the specific phenomenon actually performed. Actual heat strain can not be modeled in laboratory always, [1].

Some cycles require two separate programs application and synchronized modeling, one for temperature and one for deformation, [1].

Thermal fatigue study involves practical laboratory modeling of thermal cycles of the material that is executed a certain machine parts. In the literature, Mason has developed a model for modeling idealized thermal cycles, which were imposed later some corrections. Idealized model is embedded rigid double bar specimen, fig. 1 and for the model following assumptions have been accepted, [1],[3]:

- *bar length remains constant;*
- *field strength material bar is the same for tension and compression*
- *all thermal deformation becomes mechanical deformation when gradually bar that heats and cools within a given temperature.*

Initially, it is assumed that the rod is heated and is devoid of any tension. Thereafter the gradual cooling, ensuring then the same difference temperature "Δt" on the entire length. If at least one bar ends would be free, the bar would shorten without constraint and in this case would appear to thermal stress. But the ends are rigidly fixed by recessed that involved the effect of coercion. Under these *conditions the bar is affected by a thermal deformation constrained equal with the dilation (αΔt). Thermal tensions that occur will depend on the produced deformation (αΔt) and the deformation curve. When deformation constrained (αΔt) is less distortion of point A, for which $\sigma_A = \sigma_c$,the behavior of bar is elastic. If, the cyclic temperature variation "Δt" increases, causing a deformation constrained (αΔt) equal to the corresponding deflection point B, then AB is plastic deformation. This is materialized in the first cycle by lowering the sample temperature, [1], [3].*

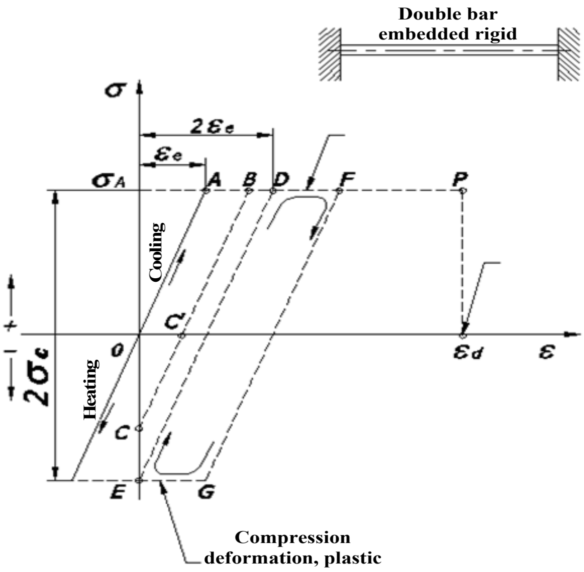

Figure 1. Idealized model of thermal cycles for modeling thermal fatigue

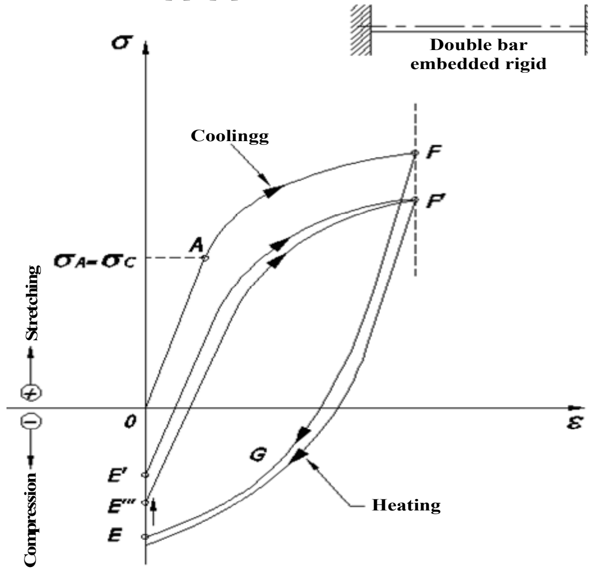

Figure 2. The corrected model for modeling thermal fatigue

The next heat begins to point B, and as temperature increases, σ decreases according to line BC'C. At some point, the status bar will be played through the point C ', for which σ = 0, but ε ≠ 0. In the bar it is found a compressive stress σ equal to the orderly. This tension due to preceding plastic flow, [1], [3].

Continuing the cycle or cooling-heating cycles under the same conditions of temperature, it will evolve between points C and B, and a new plastic flow is excluded [1],[3].

If the temperature variation "Δt" involves repeated cyclic deformation constrained twice the elastic strain, $2\varepsilon_e = \varepsilon_D$, so that when the cyclic evolution of the state bar will join the product line. Ordinates of points D and E represented σ_c, [1],[3].

Therefore, at the end of the first plastic deformation cycle is found AD (ε_e), and the new plastic flow will no longer produce. Further consider that the temperature difference "Δt" is so large that prevents dilation. Therefore, constrained thermal deformation exceeds twice of the elastic deformation ($2\varepsilon_e$) and F is the abscissa bridges. This time, as the cooling continued, the bar will evolve according to OAF line, until point A is elastic behavior of A to F plastic flow occurs. The AF segment represent the accumulated plastic strain which appeare in the first thermal cycle. Taking this first heat after heat semicircle bar evolves according to the line FG, so that the point G, its length would exceed the original length- if they have a free end - EG segment representing inelastic deformation. Since initiation of the first thermal cycle, the bar-with embedded rigid extremities - will accumulate plastic deformation constraint equal with the thermal compression EG. Continuing with the second thermal cycle, the voltage will change linearly from point E ordered, to the point D, so under the law of ED, the portion DF accumulate thermal constraint equal to DF stretching plastic deformation. In the second semicircle heating, elastic passing state bar in G F, then EG is affected by thermal constraints. a result, for each thermal cycle, which is first in the bar inelastic thermal constraints appear contradictory tension DF and EG. Plastic deformations appropriate for cyclical variables will involve failure by thermal fatigue, [1], [3].

To move closer to reality idealized model, described in figure 1 some certain corrections are necessary. The corrections are the following:

- *most of the technical metal have ecruisation effect in their deformation process, which makes "σ" not remained constant, beyond the level $\sigma_A = \sigma_c$, but gradually increase with increasing strain ε;*

- *character deforamation curve changes continuously, with cyclical changes of temperature and to cycle to another;*
- *plastic flow in one direction (tension) decreases blood flow σ for the arts comes in the opposite direction (compression), which corresponds to the Bauschinger effect; therefore EDFG loop describe in figure 1, may not have ordered sections of equal values of DF and EG, DF plastic deformation resulting in yield reduction for compression;*
- *between the two values, σ_c, corresponding sections of DF and EG is sensitive initial differences due to differences in temperature (cooling and heating);*
- *the duration of action of high temperatures, mechanical stress accumulation can not be avoided.*

The correction of thermal cycles, all of Mason developed is presented in figure 2, [1],[3].

METHODS FOR ASSESSING THE THERMAL FATIGUE LABORATORY CONDITIONS

In laboratory experimentation,the mertodology must faithfully model the application state machine body subject to thermal fatigue phenomenon. Due to assumptions that are working in the early stages of experimentation, study the phenomenon of thermal fatigue models can be made on the form of specimens or samples, etc. Thus, studying the phenomenon takes place in idealized circumstances significantly different from the real. Therefore particularly important in the choice of form geometric patterns has constructive form of evidence. After shaping the proof is to define ways of heating and cooling, taking into account the influence of geometrical and voltage concentrators, avoiding their corrosion and surface layer [6], [7].

The literature [1], suggested that to evaluate thermal fatigue resistance of materials, must take into account the following factors:

- *number of cycles of variation of temperature at the model first appearance noticeable cracks on the surface of the sample;*
- *the number of cycles of variation of temperature model to its destruction;*
- *intensity of cracks.*

Methods of testing materials subject to thermal fatigue phenomena are divided into the following categories [1], [7]:

- *stand testing, including tests carried out in actual operating conditions, specific to operation and allowing evaluation of thermal fatigue resistance or length of service availability under cyclic thermal stresses;*
- *quality testing, including tests carried out on samples and test tubes, whose shape is either cylindrical, flat, pipe or plate for determining the number of experimental thermal cycles until the first cracks caused by thermal fatigue occur on the surface of the samples;*
- *quantitative testing, including tests for experimental determination of the number of destruction thermal cycles or thermal-cyclic sustainability, and we can determine it by direct measurement or analytically; the method allows determining the dependency between the number of cycles and cycle parameters, depending on which we can assess global quantitative evaluation of sustainability of different materials subject to thermal fatigue.*

Any of the methods presented above are based on the hysteresis loop corresponding one thermal applications, the results being the isothermal tensile tests, creep and fatigue, [1], [7]. Thus, many test methods have been grouped into three categories: methods considering creep models, methods based on models and methods separate strains with models based on the concept of equivalent temperature, [1].

Whatever test methods/testing, thermal fatigue phenomena research solves two problems [1],[6]:

- *obtaining comparative data on thermal fatigue resistance in a group of materials with application to particular conditions of operation and exploitation;*
- *collecting and processing experimental data through quantifying the quantitative evaluation of resistance to thermal fatigue to enable and ensure performance.*

RESULTS

The research literature, for modeling thermal fatigue laboratory test methods was chosen as the qualitative method. This requires experimental determination of the number of thermal cycles to thermal fatigue cracks first appearance on the surface of samples made of various machine parts in the composition of internal combustion engines.

Experimental sampling mode is of particular importance for the outcome depends on the purpose of tests and their. Thus, to determine the thermal fatigue resistance, samples will be taken from fixed and mobile parts of a machine's internal combustion engines. Samples will be taken from areas representative of areas that used their. After sampling will be processed according to the outline of figure 3, after which they will be controlled in terms of dimensional. Scheme design of experimental evidence is presented in figure 4.

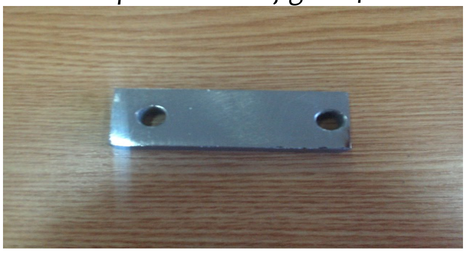

Figure 3. Testing sample

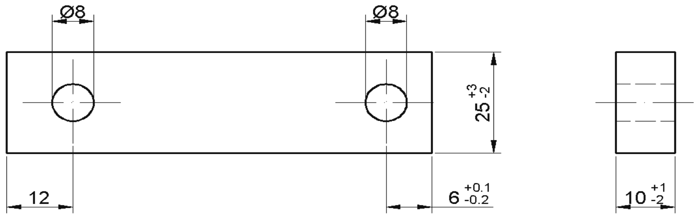

Figure 4. Construction design of a testing sample

These samples will be installed in an experimental facility which is the subject of a patent registered at OSIM A/00439 number of 17.06.2010, published in bopi_inv_12_2011.

The facility allows experimental research on thermal fatigue on common metal samples whose section has different shape and sizes. Those samples are approximately equal in size and are mounted tangentially on the generator disk. The facility provides cyclic variations in temperature of samples during intervals ordered according to the samples' material features.

Thermal cycling was used to model the correct model of Mason, whose principle modeling of hysteresis loop related to detailed in point 3 of this paper. For the conditions of the correct model was chosen Mason's constructive solution mounting evidence on the main shaft support installation on three discs, two laterals and one intermediate. Between the intermediate and lateral disc will position the bushing spacers to maintain fixed experimental evidence.

Samples are drilled at the ends properly executed installation disks channels support. In two samples placed opposite the support discs are mounted thermocouples, with corresponding response inertia working cycle of the machine parts that were performed on samples subjected to thermal fatigue regimes. This allows us to simultaneously measure and record temperature variations of the samples heated and cooled in different environments.

In figure 5 constructive fixing scheme presented experimental evidence supporting disks and intermediate side. Samples 1 is mounted on disk 2 and intermediate side support 3; strictly rigid fixation of the samples is carried out by bolts 4, 5 and nuts fastening nuts fastening 6, positioned to the outside. Thus ensuring more convenient mounting evidence supports the disc circumference.

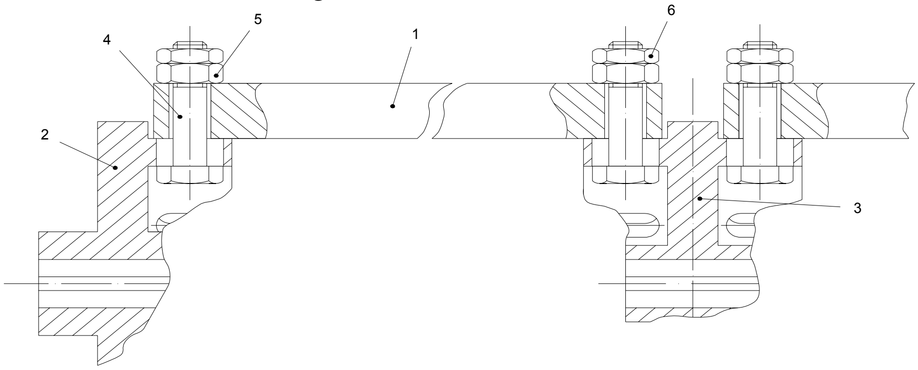

Figure 5. Construction design for experimental samples fixing on intermediate and sideward supporting disks

Experimental plant designed on the principles of thermal fatigue modeling under laboratory conditions, allowing tests on two batches of samples, each batch consisting of 12 samples each mounted tangentially to the axis of the plant.

The lots of samples are subject to cyclic heat stress regimes, aiming at the time of the first thermal fatigue cracks. Application regime is warming and then cooling their samples in different cooling media. At the upper part of the plant, above the central area of the shaft, where there are the testing samples, we mounted a semicircle electric furnace. In order to decrease the number of load cycles to fatigue cracks at the first thermal temperature may allow evidence to be as high as possible, and rapid cooling and enhanced.

Principle research involves installation of two samples placed on the circumference of the disc opposite support of Pt-Pt/Rh type thermocouples connected to a collector that sends signals termotension data acquisition system that allows recording of temperature variations in the samples experimentale In Figure 6 presents experimental evidence which thermocouples were installed in the plant for assembly and for binding to termotensiune collector.

Figure 7. Samples mounted on thermocouples

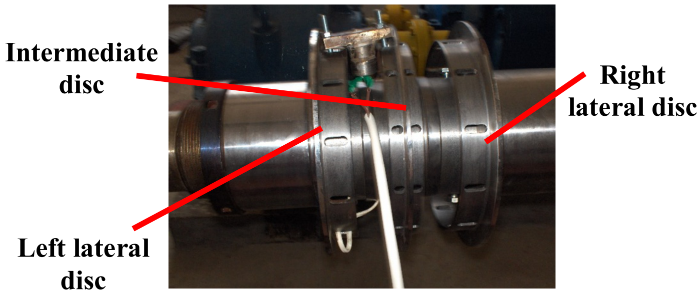

Figure 8. Assembly of samples in which a thermocouple is mounted

Following investigations into the thermal fatigue cracks most vulnerable areas are the edges of the samples, because according to the study of the technical literature the most exposed areas of fatigue cracks appearing first successions due to cyclic thermal heating-cooling concentrators are those with power.

CONCLUSIONS

Literature study on the principles, criteria and thermal fatigue research methods allowed a decision on laboratory modeling of this phenomenon with specific parts of a machine for internal combustion engines of composition. Based on the principles of modeling and qualitative method based on an installation test was performed original experimental design which allowed a real modeling thermal fatigue phenomenon.

Based on modeling principles and on qualitative method we have designed an original experimental testing installation which allowed a real modeling of the thermal fatigue phenomenon that occurs in case of machine parts of fixed and mobile machinery vehicles engines.

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