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Life behavior under thermomechanical fatigue of two types of compacted graphite iron

G. S. Oliveira, D. G. Bon, M. F. Oliveira

São Carlos School of Engineering, São Paulo University, Brazil
e-mail: guilherme_so@usp.br

Abstract

There is a great commitment of the automotive industry to develop engines with greater energy efficiency, reduced weight, reduced consumption and control of polluting gas emissions. As a consequence of this growing demand, the operating pressure and temperature of components such as the cylinder head increase. As a result, materials with greater mechanical strength and ductility are needed to manufacture these components. The thermomechanical fatigue life of the engine and other critical components of large automobiles have played an extremely important role in engine design. This work intends to relate the life under thermomechanical fatigue of two different types of compacted graphite iron, both 500 grade, as possible alternatives to the materials currently used for this purpose. The thermomechanical fatigue tests were carried out in order to simulate the activity of such components and, therefore, their cycles employ thermal gradients ranging from 50°C to 420°C. The results found are directly linked to the microstructure of the matrix and other factors, such as graphite distribution and material nodularization.
Keywords: Thermomechanical fatigue; cast iron; cylinder head.

Introduction

Thermomechanical fatigue is a limiting factor in the life of many components, such as: turbine blades used in aircraft engines, diesel engine components, cylinder head, among others [1]. This phenomenon has become a great challenge for the automotive segment, especially in engine design. Within the truck manufacturing industry, a large part of the combustion engine components are made of cast iron, this is because this material has an excellent balance between thermal and mechanical properties. These components are exposed to high temperatures (around 450°C) for long periods and undergo a large number of heating and cooling cycles (around 4000 cycles in 5 years of use). As a consequence of such cycles, the mechanical and thermal properties present in the material end up deteriorating, which causes an acceleration in fatigue damage, and which can ultimately lead to localized cracks [1].
Some works [2,3] suggest that the TMF existing in combustion engines is directly related to the start-operation-stop cycle of the engine, and not to the combustion cycle itself, in addition to sudden changes in the engine, such as for example, the oscillation from high to low torques quickly, contribute to the TMF in the components [1]. In components such as the cylinder head, some regions such as the inlet and exhaust gases are very close to each other, in this region the temperature rises quickly and due to factors such as the vehicle's cooling system and complex component geometries, the thermal expansion is restricted. This behavior gives

rise to a state of high compressive stress at high temperature, which induces plastic deformations in regions of the material where the yield limit has been reached. With engine shutdown, the temperature drops and tensile stresses are generated as a result of compressive plastic deformations, which can generate small cracks and lead the material to failure [3]. Such internal stresses generated by the engine operating cycle give rise to a very characteristic hysteresis cycle, known as out-of-phase thermomechanical fatigue.

Experimental Procedure

For the development of this work two types of compacted graphite irons were used, but with different compositions. It was a CGI500Si and a CGI500CuSn, both materials belong to the 500 grade, one with a high concentration of silicon and the other with a high concentration of copper and tin. Both materials were produced and supplied by the company Fundição TUPY S/A, established in Joinville/SC. These materials in question are manufactured to be an alternative to the materials already applied in the manufacture of automotive cylinder blocks and heads. Table 1 presents the simplified composition of the materials.

Table 1: Simplified composition of materials.

Material	%Si	%Cu	%Sn
FFV500Si	4,9 – 5,1	0,3 – 0,4	0,02 – 0,03
FFV500CuSn	2,5 – 2,6	0,9 – 1,0	0,09 – 0,10

The thermomechanical fatigue tests were carried out according to the standard ASTM E2368-17 [4]. The equipment used to carry out the tests was a servohydraulic MTS, model 810, with a capacity of 250 kN. The equipment has grips made of super cooled Ni for high temperatures, strain gauge with ceramic rods, induction coils for temperature rise and pyrometer to control the thermal cycle. Figure 1 shows the design of the specimen used for the tests.

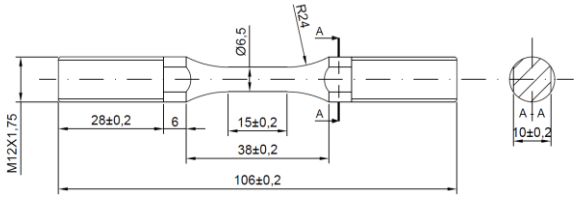

Figure 1: Specimen used for fatigue tests.

The thermomechanical fatigue test cycles employ a temperature gradient that oscillates between 50°C and 420°C and has a duration of 300s. Figure 2 shows how the strain and thermal curves behave during the tests, in this case showing two cycles.

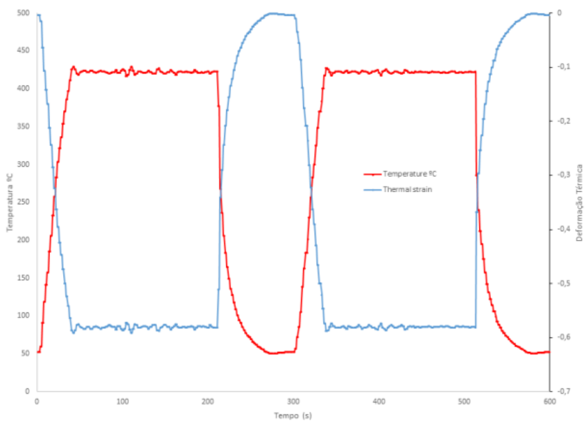

Figure 2: Thermal cycling during TMF OP test.

Results and Discussion

The results obtained for the thermomechanical fatigue tests are shown in Table 2. It can be seen that the results of the CGI500CuSn are higher when compared to the CGI500Si, in terms of life cycles.

Table 2: Results of thermomechanical fatigue tests.

Material	SP	Cycles (N)	Max Stress (MPa)
CGI500Si	1	254	397
	2	116	438
	3	237	406

Av.	-	202	413
Stan. Deviat.	-	75	21
CGI500CuSn	1	330	380
	2	484	385
	3	606	354
Av.	-	473	373
Stan. Deviat.	-	138	16

It is possible to notice that the difference between the averages obtained for the number of cycles to failure for both materials is quite large. The standard deviation tends to be high when the material studied is cast iron, this type of material is quite sensitive to the type of processing to which it is submitted, thus some factors such as graphite size and shape, as well as its distribution in the metallic matrix strongly influence their properties [5].

Conclusions

The variation found in the number of cycles is directly related to the microstructure of the matrix and its microconstituents, in addition to other factors such as graphite distribution, percentage of material nodularization and others. CGI500 CuSn has a pearlitic matrix, while CGI500 Si has a ferritic matrix, so due to the strength of pearlite being higher than that of ferrite, the material CGI500 CuSn has better behavior under thermomechanical fatigue.

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