ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

FATIGUE ANALYSIS OF A CLASS OF STEELS USED FOR THE MANUFACTURE OF VALVE SPRINGS FOR INTERNAL COMBUSTION ENGINES

Prof. Dr. Marcelo Sampaio Martins
Prof. Dr. Daniel Julien Barros da Silva Sampaio
Prof. Dr. José Geraldo Trani Brandão
Prof. Dr. José Elias Tomazini
UNESP – Campus de Guaratinguetá
Av. Ariberto Pereira da Cunha, 333
Bairro: Pedregulho
12516-410 - Guaratinguetá, SP
marcelo.sampaio@feg.unesp.br
dsampaio@feg.unesp.br

Abstract. *Steels for valve springs for internal combustion engines must support due to their application, high numbers of cycles in fatigue and can not suffer any type of failure, because that would be catastrophic for the vehicle. From these considerations, it was tested in axial fatigue, a class steel for valve springs, where he aimed to discover the values of their fatigue life, followed by an analysis of microstructural fracture surface by scanning electron microscopy. It was proved, after testing, the specimens tested broke up a number of cycles always compatible with the life work of a valve spring and that fractures always occurred by surface defects in the specimens.*

Keywords: *valve spring steel, axial fatigue ,SEM*

1. INTRODUCTION

Currently, automakers have tried to reduce the size of the valve train in internal combustion engines of vehicles for two reasons, one focused on the aspects of security for passengers and others on the need to decrease in CO_2 emissions, improving consumer fuel. In an internal combustion engine, approximately 40% of the energy lost is related to the thermal losses due to friction of its components, and from 15 to 50% of the energy lost believed to be due to the valve train (SUDA, 2005).

Thus, the reduction in size may reduce valve train friction losses and therefore reduce the fuel consumption of the vehicle. Moreover, passenger safety is increased in case of collision, therefore, the reduction in size of the engine, the space for absorbing the impact will be greater. Due to the above facts, the reduction in weight and dimensions of the valve springs become a constant challenge in the development of steel for valve springs, classified within the class of super clean steel.

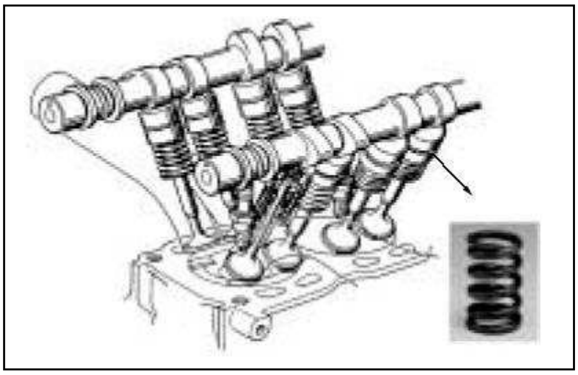

Figure 1. Arrangement of valve springs in an automobile engine (SUDA, 2005)

To meet these objectives, the valve spring, vital for the proper functioning of the engine, should be amended its geometric aspects (wire diameter and number of turns), metallurgical (number and size of non-metallic inclusions) and the same resistance to fatigue cycles the springs currently produced. This paper focuses on aspects of SAE 9258 steel fatigue produced by conventional casting (trade route) tested in axial fatigue in specimens standardized by ASTM E 466, in steel samples taken during the lamination (bars 14.79 mm diameter). Were analyzed further fractures, coming from the trials, with the aid of electron microscopy (SEM).

ISSN 2176-5480

2. HISTORICAL DEVELOPMENT OF STEEL FOR SPRINGS VALVES INTERNAL COMBUSTION ENGINES

Springs for dynamic applications are components subjected to severe conditions of use at high temperatures (about 230 ° C) and under high cyclic request. The trend in the automotive industry is the production of high-performance engines, with springs ever lighter and higher mechanical strength (OLIVEIRA, 2007).

Wire of piano wire were produced in Sweden and have been widely used in engine valves, after the second world war. Japan, from the 30s, began studies in this area, and in 1952 managed to produce wire rod similar to that produced by Swedish steel. In 1955, the United States began using tempered steel wires Cr-V springs for their internal combustion engines. Steel springs for the series Cr-Si, tempered in oil, which have a higher mechanical strength than the Cr-V Series (SAE 9254, JIS SWOSC-V) started to be used in 1964 and remained in use until the present day . Table 1 compares the chemical compositions of steels for valve springs, and figure 2 shows the progress of this development briefly (SUDA, 2005).

Table 1. Chemical composition of wire rod for valve spring (SUDA, 2005)

Types of Steels	(JIS)	%C	%Si	%Mn	%Ni	%Cr	%V	Grade
High Cr-Si-V	High Strength Steel	0,56 - 0,61	1,80 – 2,20	0,70 - 1,00	0,20 - 0,40	0,85 – 1,05	0,05 – 0,15	KHV10N
Cr-Si-V	High Strength Steel	0,60 - 0,65	1,30 – 1,60	0,50 - 0,70	-	0,50 – 0,70	0,08 - 0,18	KHV7
Cr-Si	SWOSC-V	0,51 - 0,59	1,20 – 1,60	0,50 - 0,80	-	0,50 – 0,80	-	SAE 9254
Cr-V	SWOCV-V	0,45 - 0,55	0,15 – 0,35	0,65 - 0,95	-	0,80 – 1,10	0,15 - 0,25	SAE 6150
Carbon Steel	SWO-V	0,60 - 0,75	0,12 – 0,32	0,60 - 0,90	-	-	-	SAE 1070

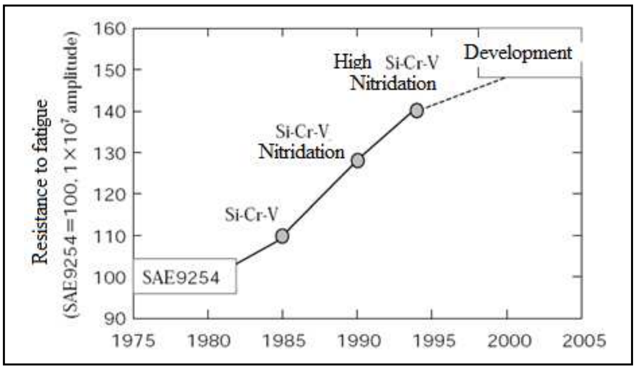

Figure 2. Development of valve springs steels. (SUDA, 2005)

In early 2000, Japanese steelmakers had several developments in steel for valve springs, for example, steel KHV10N. Currently, Japanese steelmakers develop a new generation of steels for this application. Figures 3 show important mechanical properties compared to other steels for valve springs. We observe dimensional changes that the springs have suffered due to the technological advances already commented (SUDA, 2007).

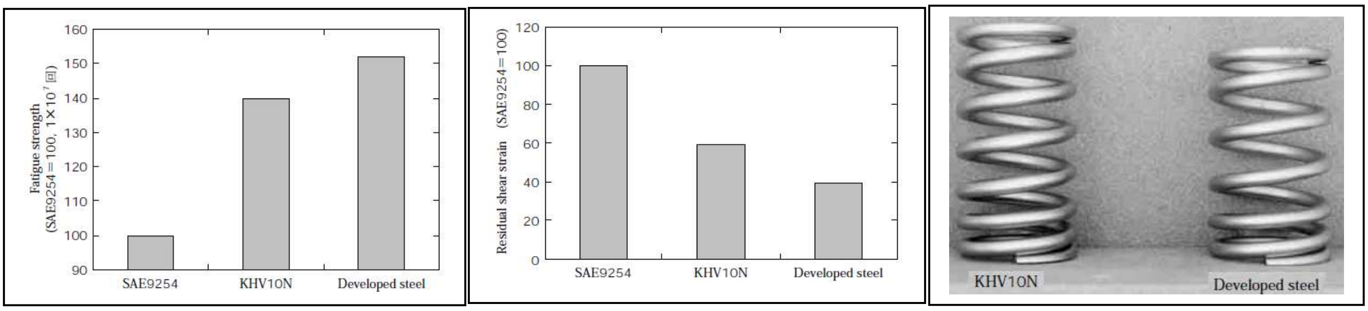

Figure 3. Fatigue strength of steel for valve springs, shear stress residual steel for valve springs and changes in the diameter and number of turns in coil springs valves manufactured with the new generations of steel (SUDA, 2007).

ISSN 2176-5480

3. EXPERIMENTAL PROCEDURE

3.1 Fatigue Tests

The axial fatigue test (ASTM E 466) is indicated when the parameter being controlled is the deformation in the test, or for those cases in which the strain or deformation should be uniform section of the test specimens. Fatigue Tests with axial loads, in general, are indicated to evaluate the influence of the metallurgical conditions of the material in fatigue resistance. Axial Fatigue tests (R = 0.1) were performed on Instron 8801 machine, using specimens made according to ASTM E 466 (Figure 6). Were three fatigue tests for each stress level (80%, 70%, 60% and 50% of the yield stress found in tensile test).

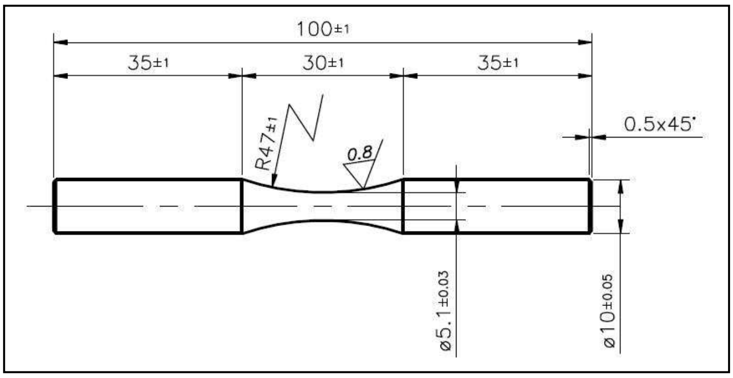

Figure 6. Specimens for axial fatigue test (ASTM E 466)

The specimens were prepared according to ASTM E 466 and surface finish was kept similar to that of the wire produced industrially. Initially, all diameters were measured from the lowest section of the specimens. During the tests, so the specimens were broken, the fracture surfaces were protected with varnish, to prevent oxidation and protect the surface for subsequent fracture analysis.

3.2 Analysis of the fracture surface by scanning electron microscopy

The fracture surfaces of the specimens fatigue axial tested machine Instron 8801, were examined with the aid of scanning electron microscopy, using a scanning electron microscope (SEM) JEOL JSM-6490 LV Scanning Electron Microscope - Oxford Instruments. The purpose of these analyzes was to observe in more detail the fracture surfaces, to try to identify the mechanisms involved in fatigue fracture of the steel produced by the production route by conventional casting, and used three specimens of different stress levels. The fracture surfaces were cleaned with acetone to remove the protective lacquer, before being placed in the vacuum chamber of the SEM.

4. RESULTS

4.1 Results of measurements of the roughness of the specimens

For the specimens used in fatigue tests axial profiles found on the surface roughness shown in Table 2.

Table 2. Surface roughness of the specimens for axial fatigue tests (SAE 9258 steel quenched and tempered).

Roughness	Results	Media
Ra	0,70; 0,75; 0,76	0,74

4.2 Results of the fatigue tests axial

The axial fatigue tests were performed on standard specimens with surface finish similar to the wire industrially produced by conventional casting routes. Stress levels used were 80%, 70%, 60% and 50% of the average yield tension found in the tensile tests. Table 3 shows the results of fatigue tests axial specimens produced by the conventional route.

ISSN 2176-5480

Table 3 - Results of axial fatigue tests performed on specimens produced from conventional casting route.

Specimens SAE 9258 (Convention route)			
Stress (MPa)	**Number of Cycles**	**Media**	**Standard Deviation**
1338,4	6.815	20.012	15.295,4
1338,4	14.626		
1338,4	16.536		
1338,4	42.071		
1171,1	122.995	87.140	37.468,9
1171,1	46.038		
1171,1	114.493		
1171,1	65.035		
1003,8	52.606	138.287	94.236,3
1003,8	61.691		
1003,8	207.877		
1003,8	230.972		
836,7	407.193	452.961	108.917,9
836,7	591.099		
836,7	478.000		
836,7	335.549		

For the construction of the S-logN curve (Figure 7), referring to the axial fatigue tests for specimens produced by conventional casting, we used the average values of cycle numbers for each stress level, with its standard deviation, as indicated in Table 4.

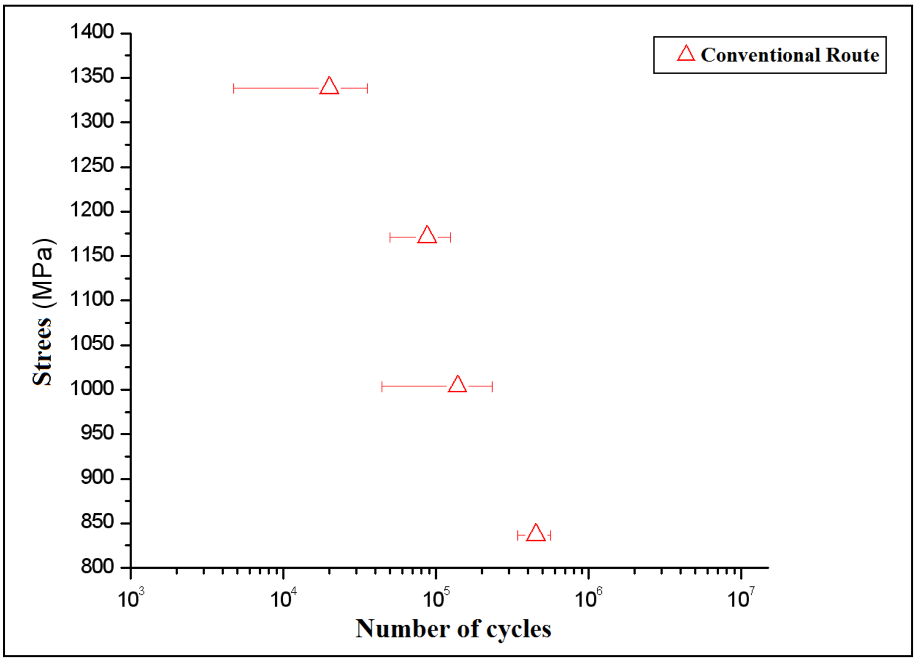

Figure 7. S-logN curve related to axial fatigue tests performed on specimens obtained from wire rod produced by conventional casting.

Were also conducted fatigue tests on a plot of axial specimens (conventional casting) with surface roughness (Ra = 1.2) higher than the roughness of the wire produced industrially, to verify the effect of surface finish on the fatigue strength of steel in the form of wire rod. Table 4 presents the results found in fatigue tests for roughness Ra = 1.2.

ISSN 2176-5480

Table 4. Results axial fatigue test performed on specimens produced from the conventional route of casting surface finish (Ra = 1.2) different from commercial.

Specimens SAE 9258 (Rota convencional) (Ra = 1,2)			
Stress (MPa)	**Number of Cycles**	**Media**	**Standard Deviation**
1505,7	4.605	7.122	2.795,1
1505,7	10.130		
1505,7	6.630		
1338,4	8.822	9.623	757,5
1338,4	10.328		
1338,4	9.719		
1171,1	15.176	14.124	1.488,4
1171,1	13.071		
1003,8	55.581	55.581	0,0
836,7	219.886	219.886	0,0

The Figure 8 shows graphically the result of fatigue behavior for axial specimens obtained wire rod with surface roughness (Ra = 1.2) higher than the average surface roughness of the wire obtained industrially (Ra = 0.8, Table 3) and specimens of wire used in fatigue tests of this paper (Ra = 0.7, Table 2). Analyzing the Figure 8 it can be seen that the fatigue behavior for specimens produced by conventional casting (with better surface finish), which represents the industrial finishing wire is slightly higher compared to the rougher finish for all levels stress.

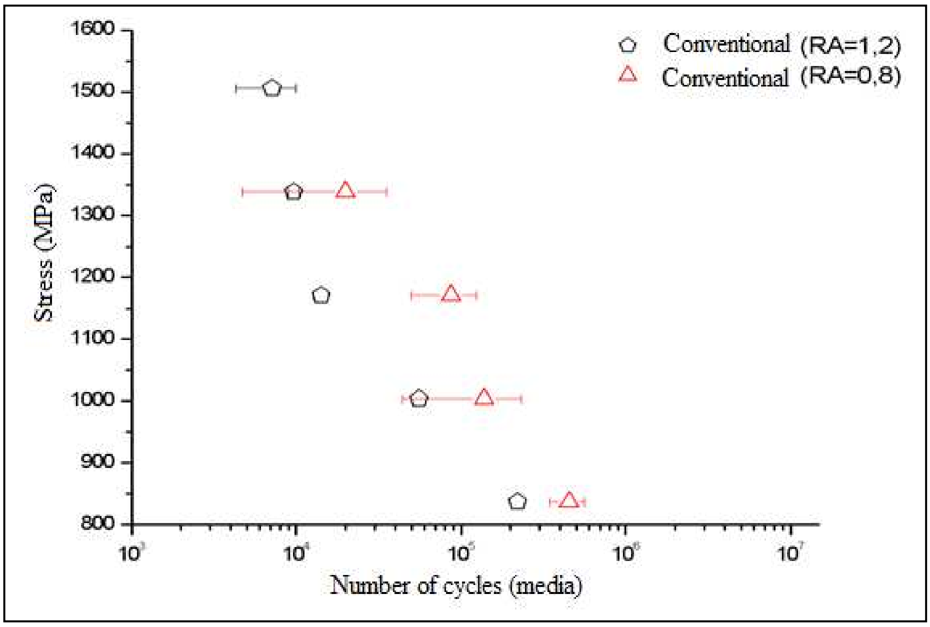

Figure 8. S-logN curves showing the effect of surface roughness on fatigue behavior in axial specimens obtained wire rod produced by conventional casting.

4.3 Results of fractography obtained with scanning electron microscopy of the surface of specimens fractured by axial fatigue

Were obtained images of the fractured region during axial fatigue tests (with the aid of SEM), for the condition of manufacturing of wire rod by conventional casting, for the four Stress levels studied. Figure 9 (a), (b), (c) and (d) refer to the fatigue fracture surfaces of the specimens requested with stress level of 50% of the yield stress in the following magnifications: 20 X , 150 X, 500 X and 1000 X.

ISSN 2176-5480

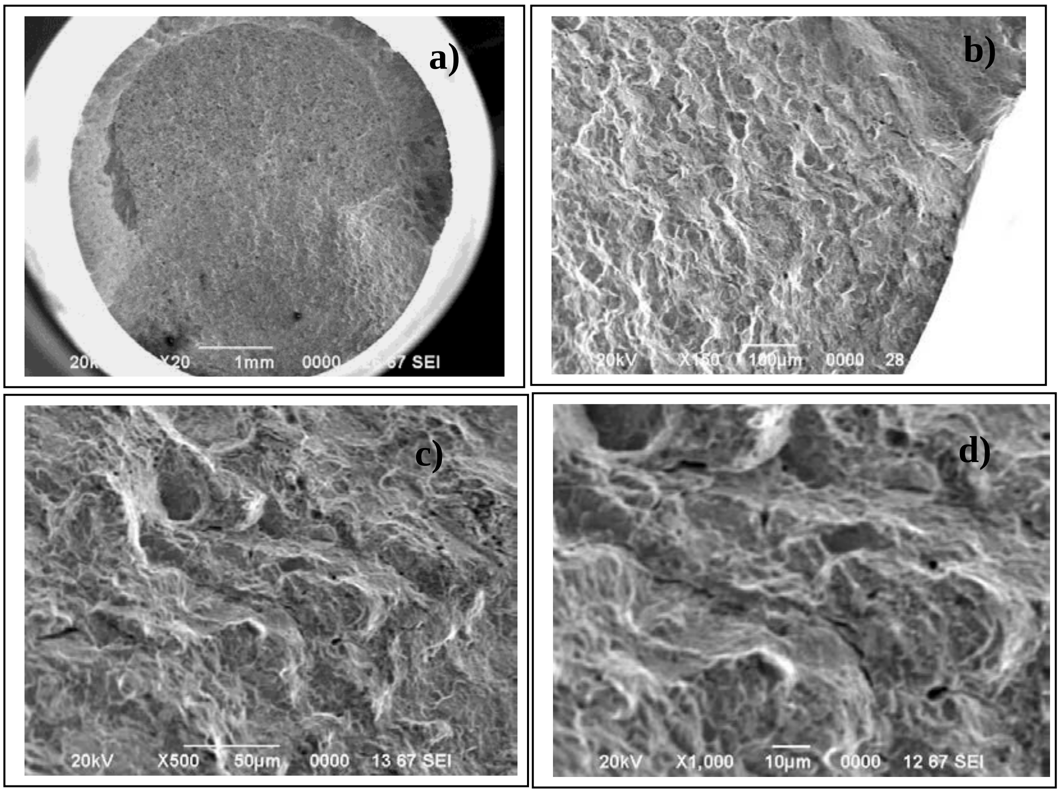

Figure 9. Fracture for 50% of the yield stress, showing the fatigue fracture surfaces with magnifications: 20X (a) 150X (b) 500X (c) 1000X and (d)

Observe the appearance of ductile fracture surface of the material, the presence of microcavities. Note also the presence of dispersed cracks in fracture surfaces. In the cases shown, the fracture originated from different points in the surface of the test piece does not occur due to fracture inclusions. Figure 10 refer to the fatigue fracture surfaces of specimens requested with stress levels of 70% of the yield stress in the following magnifications: 20X, 150X and 1000X.

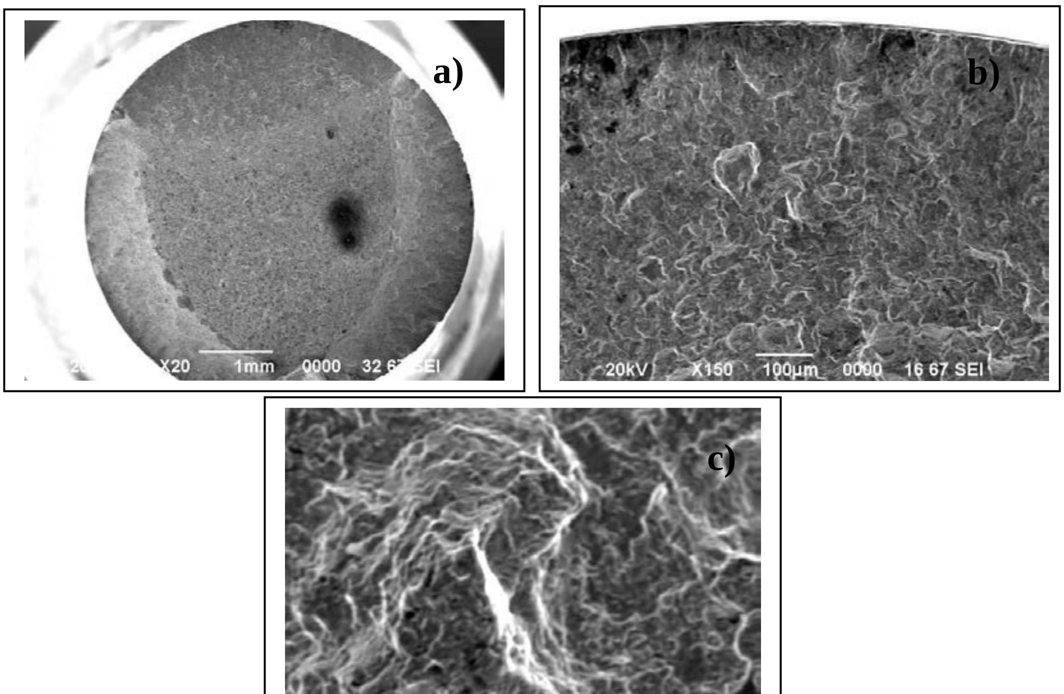

Figure 10. Fracture for 70% of the yield stress, showing the fatigue fracture surfaces with magnifications: 20X (a) 150X (b) 1000X and (c)

ISSN 2176-5480

In all cases analyzed by scanning electron microscopy (SEM), it is observed that the fractures were initiated at points on the surface of the specimens. This characteristic of fractures according Bathias (2001) is typical of tests performed between low cycle fatigue (10^4 cycles) and high cycle (10^6 cycles). The aspects of initiation of fatigue cracks obtained from this study is presented morphologically similar to studies Bathias (2001), or to low numbers of cycles to initiation of the fracture started from several fronts propagating, as can be seen in Figures 9 and 10.

According Bathias (2001), this finding on early fatigue fractures is not a rule, but is a general consensus that cracks initiated from 109 cycles (giga cycles), usually begin from internal defects. As steel for valve springs SAE 9258 belongs to a class of super clean steels, the prevalence for early fatigue cracks on the surface of the material becomes greater than internally. According Bathias (2001), in the regime of giga cycles, internal defects or variations in grain size of the material compete with surface defects, to be the cause of fatigue fractures. Of the probabilistic point of view, it is clear that the greater presence of defects concentrated inside the material, in relation to its surface. However, if the defect density is higher at the surface, a competition can occur between the surface and the interior of the material, and the fracture initiation may occur by the surface. This is what was observed in this study.

5. CONCLUSIONS

The results of axial fatigue tests performed on specimens of conventional casting in two lots differing in their surface finish (Ra = 0.74 and Ra = 1.2), confirm what is already known from the literature, showing that, as better the surface finish, the better the fatigue life. Fractography analyzes were performed using scanning electron microscope (SEM) in some specimens, tested in axial fatigue. In all the images obtained, are not differences in the appearance of the fracture of the specimens tested. It is also evident the absence of inclusions in the analyzes. Due to the level of cleanliness of the internal steel, all fractures occurred during the endurance test axial-started from the surface of the material, which makes validating according Bathias (2001) theories and methods presented in this paper

6. REFERENCES

Bathias, C, 2001. How and why the fatigue s-n curve does not approach a horizontal asymptote. France, International Journal of Fatigue, Elsevier.

Suda, Sumie; et al., 2005. The past and future of high-strength steel for valve spring. Japan, Kobelco.

Suda, Sumie, et al.,2007 Super high strength valve spring with excellent fatigue and sag resistence. Japan, Kobelco.

Oliveira, D.C, Leandro, C., 2007 Desenvolvimento e evolução do aço para mola na Aços Villares. Brasil, 62° Congresso Anual da ABM.

7. RESPONSIBILITY NOTICE