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EFFECT OF THE SURFACE FINISH ON HCF IN STEELS: A THERMOGRAPHIC APPROACH

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ABSTRACT

In this paper both theoretical background and experimental results are presented to investigate the effect of the surface finish on life of steel samples undergoing high cycle fatigue (HCF). Three groups of specimens with different surface finishing and three groups of grinded specimens have been prepared and fatigue tested. Surface temperature measurements of specimens during tests have been compared. Results have been discussed and analyzed basing on the main HCF damage models of steels.

Keywords: fatigue, thermography

INTRODUCTION

The effect of surface finish on high cycle fatigue behavior of steels has been widely experimentally investigated during the decades. Traditional experimental approaches have been used to investigate the influence of surface finish on fatigue limit. That is the fatigue limit of sets of specimens with various surface roughness have been assessed by means of experimental loading of specimens. The fatigue limits thus obtained are compared resulting in measuring the influence of surface roughness on fatigue limit. The causes of this influence are investigated mainly by means of microscopy that is investigating fracture surface and fatigue crack growth. As an example in [Itoga et al.] a deep study on the effect of surface roughness on fatigue life of high resistance steels by means of traditional experimental investigation (bending rotation fatigue tests) on the fatigue limit, microscopic analysis of fracture surfaces. A particular attention is dedicated to the transition phase between superficial and subsuperficial crack nucleation. In this and other papers it is stated that surface roughness acts as a small defect and a parameter related to the defect size is proposed to predict the fatigue limit. In [Javidi et al.] the effects of surface roughness and residual stresses on fatigue life are compared for a steel alloy with the same methods.

In [Kasarekar et al.] the effect of surface roughness on fatigue life in contact problems is investigated by means of a Smith Watson Topper multiaxial damage approach and it results that surface roughness increments the value of the damage parameter.

Generally speaking, the thermographic approach to the analysis of fatigue of steels has been utilized from the eighties by several international research groups.

The general fatigue damage approach described by [Doudard et al.] predicts a damage due to microplasticization statistically activated related to load amplitude and cycles. In that paper the thermographic approach well adapts to measure the effect of energy dissipation due to microplasticization in elastic loading.

In the present paper the effect of surface finish on HCF life of steels has been investigated by means of thermography. In technical literature the authors did not found any report about this topic.

In particular, a damage accumulation approach is proposed. According to [Javidi et al.], surface roughness can be considered as a microcrack. A microplasticization field is located at the edge of a crack, even if load is in the elastic field. The thermal increment measured on the specimen surface (same material, same loading condition, different surface roughnesses) may be generated only by the microplasticization located at the edges of the roughnesses. This way, the thermal increment can be a parameter to assess the fatigue limit of rough specimens, according to the Doudard hipothesis.

MATERIALS AND METHOD

The investigated material is a C45 commercial steel. It has been previously characterized by means of tensile testing according to [UNI EN 10002] and fatigue testing (R=-1) according to [ASTM E 466-72].

C45 specimens have been obtained by cutting and milling from a 4 mm thick sheet. Specimens have been finished by means of different values of surface roughness: grinding (Ra=0,8) and A (Ra=2,6), B (Ra=2,8) and C (Ra=3,5) The last three values of surface roughness have been obtained by means of sand paper on grinder specimens, while the first one has been obtained by means of machining. The values of surface roughness have been obtained on all specimen surfaces.

Three loading values have been selected below and above the fatigue limit value of the grinded specimens: 210, 230 and 250 MPa.

Preliminary fatigue testing and the present fatigue tests have been run on a servo hydraulic testing machine, a Instron 8801, load cell Dynacell 2527 100 kN, hydraulic grips.

Specimens have been fatigue tested (R=-1) for 2 millions of cycles. The first 5000 cycles are performed at 10 Hz while the lasting cycles at 30 Hz. This way it is possible to investigate the thermal behavior in two loading frequency conditions. three specimens have been tested for each test configuration except for grinded specimens for which, due to the high repeatability of thermal measurements, only one specimen has been tested for each loading level.

Specimens shape is designed according to [ASTM E 466-72] and it is plotted in Figure 1.

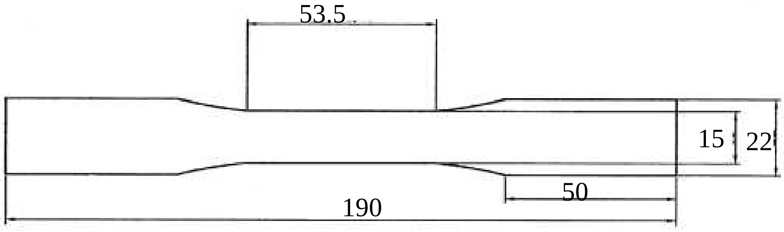

Fig. 1 Specimen geometry. Dimensions in mm

During fatigue testing, specimens surface temperatures have been digitally acquired by means of a Thermo Tracer TH5104 NEC system. To maximize infrared emission specimens have been black painted obtaining a superficial emission coefficient equal to 0.9 or higher. In Figure 2 the experimental setup is shown.

This way the effect of surface finish on thermal measurement has been controlled by means of black painting. In fact the black coating fills the roughness surface microcracks and for temperature measurements the surface results to be flat and grinded like. The specimen thermal emissivity has been thus checked so that surface roughness does not affect temperature measurements.

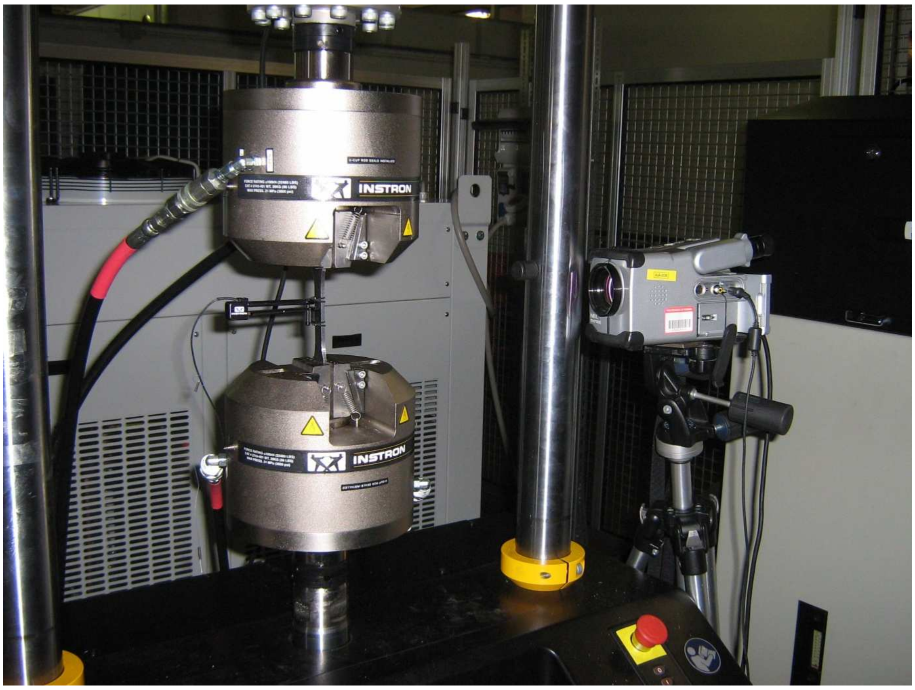

Fig. 2 Experimental setup.

Reference temperature (ambient temperature) is defined as the surface temperature of a flat steel plate, black painted, not loaded, put in the thermotracer focus area and captured in the same frame with the specimens.

Thermal results have been PC processed by means of a dedicated software, MikroSpec and a dedicated software developed by the authors research team. This software has been described in previous papers of the same authors and subsequently other modules have been added.

The difference between surface maximum temperature and reference temperature (ΔT) versus time have been plotted for each specimen.

The temperature level for which a plateau can be set, is defined as stabilization temperature $\Delta T_{stab.}$

RESULTS AND DISCUSSION

Preliminar tensile and fatigue testing (R=-1) of C45 results are reported in the following Table 1.

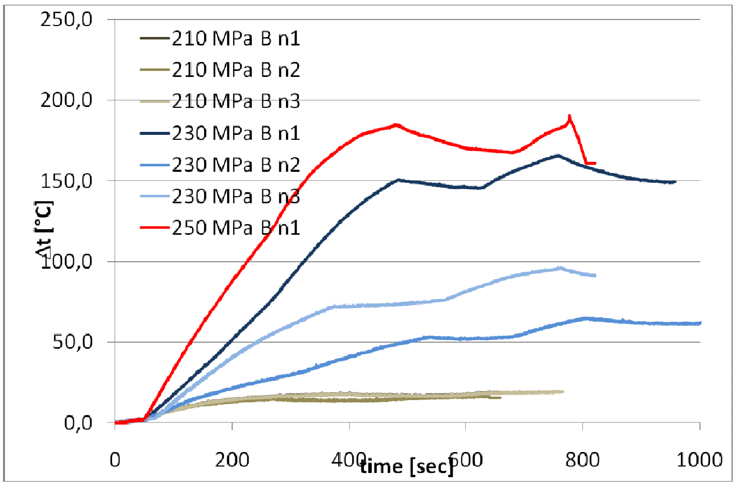

Fig. 3 Specimens surface maximum temperature trends. Specimens B

Table 1 Uniaxial tension static and fatigue (R=-1) test results

	E_I [(N/m)x1000]
R_{p02}	520 MPa
σ_{D-1}	240 MPa
E	200-220·10^3 MPa
ρ	7870 kg/m^3

In Figure 3 a typical trend of ΔT is plotted, as an example, for B specimens. The change in frequency domain can be seen in the step of the curves.

Table 2 Fatigue testing results: ΔT_{stab} [℃]

Alternate stress [MPa]	**A 10 Hz**	**A 30 Hz**	**B 10 Hz**	**B 30 Hz**	**C 10 Hz**	**C 30 Hz**	**grind 10 Hz**	**grind 30 Hz**
250	38,1	208,3	1,7	172,2	3,7	69,4	0,5	60,0
	27,4	174,7	1,8	185,0	4,6	103,8		
	2,2	161,8	1,6	165,4	4,9	87,2		
mean (250 MPa)	**22,6**	**181,6**	**1,7**	**174,2**	**4,4**	**86,8**	**0,5**	**60,0**
230	6,5	128,2	1,2	156,8	4,0	54,0	0,3	37,4
	12,7	128,6	1,2	75,0	5,9	26,9		
	2,9	131,0	1,2	93,4	4,8	54,0		
Mean (230 MPa)	**7,4**	**129,3**	**1,2**	**108,4**	**4,9**	**45,0**	**0,3**	**37,4**
210	7,6	46,7	1,2	17,1	2,5	37,5	0,1	25,0
	7,5	50,7	1,0	14,9	1,2	51,4		
	7,4	43,3	1,2	17,8	1,6	45,0		
mean (210 MPa)	**7,5**	**46,9**	**1,2**	**16,6**	**1,8**	**44,6**	**0,1**	**25,0**

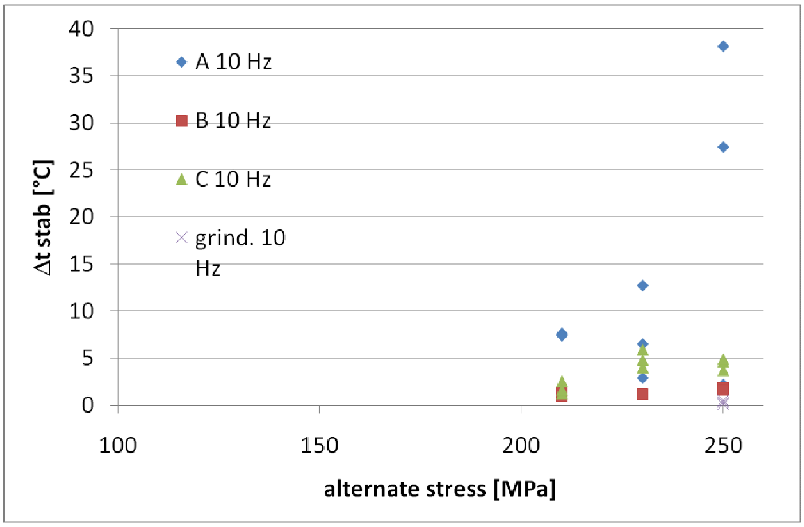

Fig. 4 ΔT_{stab} 10 Hz

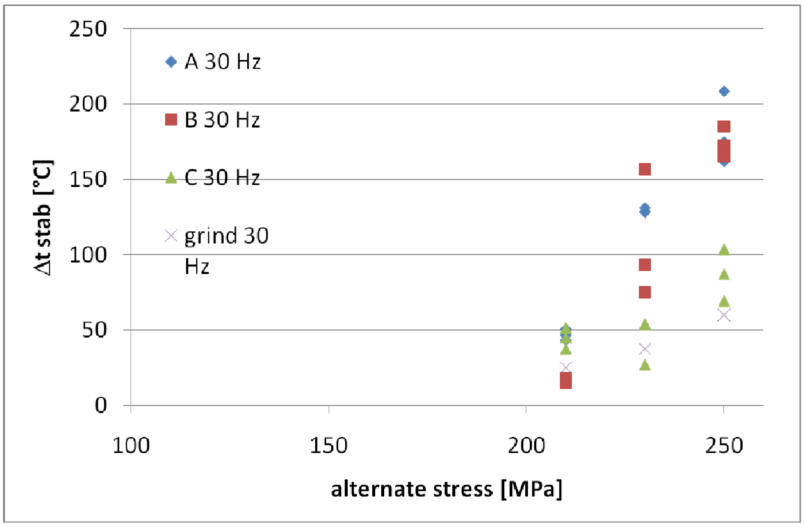

Fig. 5 ΔT_{stab} 30 Hz

In Table 2 ΔT_{stab} values obtained for the different specimens are reported.

In Figure 4 and 5 the same results are plotted.

Table 3 shows the cycles to failure Nf for the same specimens.

In Figure 6 and 7 the ΔT_{stab} vs Nf are plotted respectively for 10 and 30 Hz measurements.

Table 3 Fatigue testing results: N_f

Alternate stress [MPa]	**A**	**B**	**C**	**grinded**
	3110	17480	11549	
250	4650	26016	5005	35160
	4283	22940	14207	
Mean (250 MPa)	**4014**	**22145**	**10254**	**35160**
230	74176	72486	38883	
	125415	70614	11354	2000000
	76894	47052	23400	
mean (230 MPa)	**92162**	**63384**	**24546**	**2000000**
	1015936	2000000	37276	
210	1269345	2000000	2716	2000000
	987650	2000000	15920	
mean (210 MPa)	**1090977**	**2000000**	**18637**	**2000000**

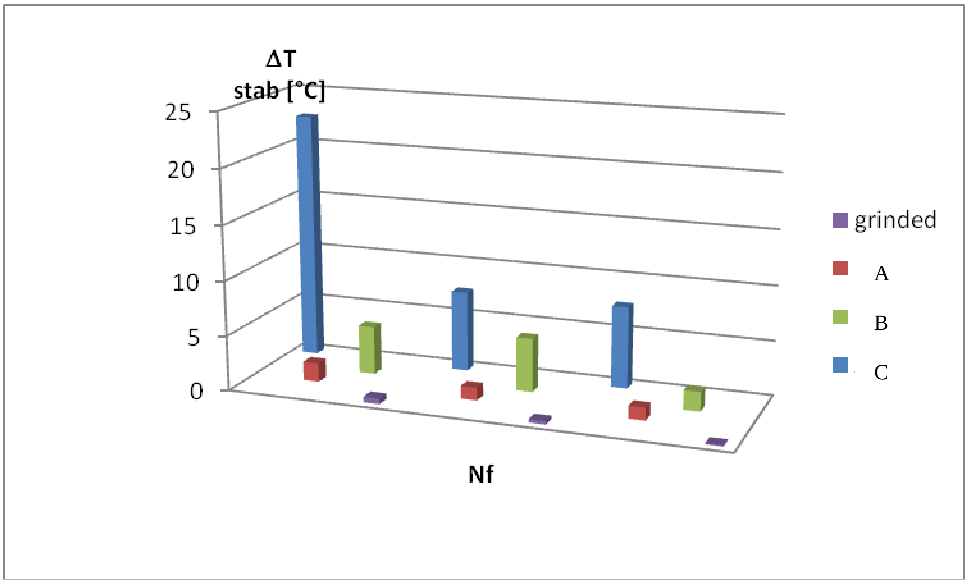

Fig. 6 ΔT_{stab} vs cycles to failure. 10 Hz

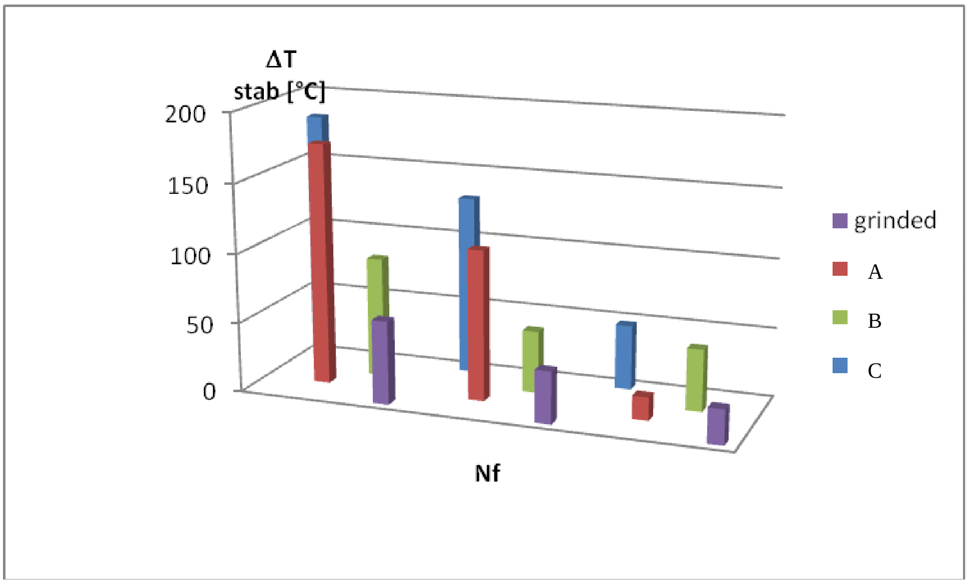

Fig.7 ΔT_{stab} vs cycles to failure. 30 Hz

The fatigue life of specimens results to be affected by surface finish, as expected and predicted in literature. When surface roughness increases, experimental life shortens and stabilization temperature level, ΔT_{stab}, increases. The most relevant result is that the thermal increment of specimens appear to be affected by surface roughness for the same load amplitude. This can be due to the fact that traces left on the surface, when surface roughness is obtained, act as nucleation sites for microplasticization located on the surface, thus leading to a macroscopic temperature increase.

CONCLUSION

In the present paper, the possibility of analysing the effect of the surface finish on HCF life of steels frao the thermographic point of view has been investigated.

The obtained results show that the thermographic approach can be applied to the investigation of the effect of surface roughness on high cycle fatigue life of steels. Thermal increment can be related both to cycles to failure Nf and to surface roughness. It is also an experimental validation of the microplastic damage model proposed by Doudard et al. Following research activities will be focused on two aspects.

First of all to quantitatively correlate thermal surface increment of specimens with surface roughness and fatigue limit changes due to surface roughness. The second topic will investigate both from an analytical and an experimental point of view the relation between microplasticization, damage increment and surface roughness.

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