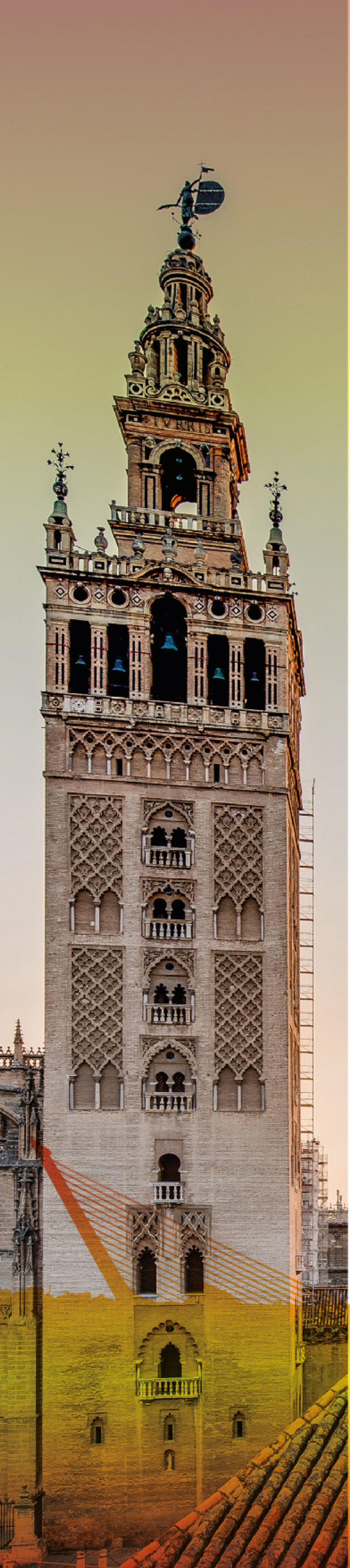

Book of Abstracts

9th Symposium on Fretting Fatigue

ISFF9

SEVILLE
april 1st to 3rd, 2019

www.isff9.org

INDEX

Welcome

Dear colleague,

It is a pleasure for me to invite you to participate in the **9th International Symposium on Fretting Fatigue (ISFF9)** to be held in the city of Seville (Spain) from April 1st to 3rd, 2019.

The objective of this symposium is to share the latest developments in the f ield of fretting fatigue/wear by scientists and engineers from all over the world. This is the 9th edition in a series of successful symposiums dedicated to this topic held every three years. The main topics of the ISFF9 are the following:

- Experimental results in fretting fatigue/wear
- Theories and mechanisms of fretting fatigue/wear
- Modelling in fretting fatigue/wear
- Applications and case studies
- Palliatives against fretting fatigue/wear

Also, different types of points of view should contribute to the conference, from academic and industrial practitioners, building a bridge between these areas of expertise.

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SCIENTIFIC PROGRAM

MONDAY 1/4/2019

TIME	ROOM	TITLE	AUTHORS	CODE
09:00-09:30	SALÓN DE GRADOS	RATIONALISING THE EFFECT OF TEST PARAMETERS IN GROSS-SLIP FRETTING WEAR TESTING – ILLUSTRATIONS FROM THE FRETTING OF STEEL CONTACTS	**PHILIP SHIPWAY**	0067
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09:30-09:50	SALA DE JUNTAS	A NOVEL ACCELERATION CONTROLLED RANDOM VIBRATION FRETTING TEST METHODOLOGY: FROM CLASSICAL SINE TO GAUSSIAN RANDOM PROCESSES	DE PANNEMAECKER - **ATTIA** - WILLIAMS	001
09:50-10:10		FRETTING WEAR EXPERIMENTAL ANALYSIS OF A R3 OFFSHORE STEEL AGAINST A PC/ABS BLEND	PANDIM – **DOCA** – ANDRADE PIRES	0029
10:10-10:30		STUDY ON THE DAMAGE MECHANISM OF TORSIONAL FRETTING FATIGUE	**PENG** / WANG / XU / CAI / WEN / ZHU	006
10:30-10:50		FRETTING CORROSION BEHAVIOR BETWEEN ALLOY 690 AND ITS SUPPORTING MATERIALS IN STEAM GENERATOR IN PWR	**MING** / LIU / WANG / ZHANG / HAN	0031
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09:50-10:10		WEAR RESISTANCE OF STEELS AFTER COMBINED LASER THERMAL AND SHOCK-WAVE HARDENING	BRAGOV / **LAMZIN** / LITVINCHUK / LOMUNOV / RUSIN	0045
10:10-10:30		EFFECTS OF SHOT PEENING ON THE FRETTING FATIGUE BEHAVIOUR OF AL 7075-T651	MARTÍN / VÁZQUEZ / NAVARRO / DOMÍNGUEZ	0070
10:30-10:50		VOIDS AS STRESS RELIEVERS IN A SHRINK-FITTED SHAFT	**ERENA** / VÁZQUEZ / NAVARRO / DOMÍNGUEZ	0068
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11:40-12:00		FATIGUE OF TWO CONTACTING WIRES OF THE ACSR IBIS 397.5 MCM CONDUCTOR: EXPERIMENTS AND LIFE PREDICTION	ROCHA / DIAZ / SILVA / ARAÚJO / FERREIRA / **CASTRO**	0021
12:00-12:20		FRETTING FATIGUE CRACK PATH AND LIFETIME ESTIMATION IN AL7075 ALUMINIUM ALLOY	**ZANICHELLI** / CARPINTERI / VANTADORI	007
12:20-12:40		A DAMAGE MODEL FOR FRETTING USING SEMI-ANALYTICAL METHOD	BEYER / CHAISE / LEROUX / **NELIAS**	0012

TIME	ROOM	TITLE	AUTHORS	CODE
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11:40-12:00	SALÓN DE GRADOS	EXPERIMENTALLY ANALYZING WEAR RESISTANCE OF COMPACTED FINE-DISPERSED IRON POWDER AND WOLFRAM MONOCARBIDE NANO-POWDER PRODUCED BY IMPULSE COMPACTION	**IGUMNOV** / BRAGOV / KONSTANTINOV / LOMUNOV / RUSIN	0041
12:00-12:20	SALÓN DE GRADOS	FORMATION AND CHARACTERIZATION OF CRACKS AND DEGRADATION LAYERS IN LARGE FLAT-ON-FLAT FRETTING CONTACT	JUOKSUKANGAS / NURMI / HINTIKKA / MÄNTYLÄ / **LEHTOVAARA** / VIPPOLA / HONKANEN/ VAARA / FRONDELIU	0042
12:20-12:40	SALÓN DE GRADOS	EFFECT OF VELOCITY ON THE IMPACT- SLIDING FRETTING WEAR BEHAVIOR OF 304 STAINLESS STEEL	YIN / **CAI** / YU / PENG / ZHU	0050
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14:50-15:10	SALA DE JUNTAS	NUMERICAL CORRELATION BETWEEN ACOUSTIC EMISSION AND FRETTING REGIME TRANSITION	**WADE** / CLARKE / COPLEY / AL SHEIKH OMAR / BRYANT / LISKIEWICZ	0017
15:10-15:30	SALA DE JUNTAS	INVESTIGATION OF EARLY CRACK ORIENTATION IN 7050-T7451 ALUMINUM ALLOY UNDER FRETTING CONDITIONS	**ALMEIDA** / CASTRO / ARAÚJO / CARDOSO	0020
15:30-15:50	SALA DE JUNTAS	PRELIMINARY STUDY ON THE USE OF THE THEORY OF CRITICAL DISTANCES WITH MESH CONTROL FOR FRETTING FATIGUE LIFE ESTIMATION	ZABALA / INFANTE/GARCIA / GINER / GOEL / ENDRINO / **LLAVORI**	0040
PARALLEL SESSION 3		**APPLICATIONS AND CASE STUDIES**		
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14:50-15:10	SALÓN DE GRADOS	FRETTING IN NUCLEAR POWER SYSTEMS : A REVIEW	CAI / **ZHU**	0049
15:10-15:30	SALÓN DE GRADOS	A GLOBAL-LOCAL FRETTING ANALYSIS METHODOLOGY AND DESIGN STUDY FOR THE PRESSURE ARMOUR LAYER OF DYNAMIC FLEXIBLE MARINE RISERS	**LEEN, SEAN** / O'HALLORAN, S.M. / HARTE, A.M. / CONNAIRE, A.D.	0065
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TIME	ROOM	TITLE	AUTHORS	CODE
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17:00-17:20	SALA DE JUNTAS	FRETTING FATIGUE UNDER VARIABLE AMPLITUDE LOADING, PART 1: NUMERICAL ANALYSIS	**PINTO** / ARAÚJO / TALEMI / CARDOSO	0038
17:20-17:40	SALA DE JUNTAS	CRYSTAL PLASTICITY FINITE ELEMENT MODELLING OF MICROSTRUCTURE EFFECTS IN FRETTING FATIGUE FOR FLEXIBLE MARINE RISERS	ASHTON / HARTE / O'HALLORAN / **LEEN**	0030
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16:40-17:00	SALÓN DE GRADOS	FRETTING WEAR BEHAVIOUR OF COBALT-BASED SUPERALLOYS AT HIGH TEMPERATURE– A COMPARATIVE STUDY	KORASHY / **ATTIA** / THOMSON / OSKOOEI	0057
17:00-17:20	SALÓN DE GRADOS	STUDY OF SIZE EFFECTS IN FRETTING FATIGUE	**ARAUJO**	0061
17:20-17:40	SALÓN DE GRADOS	FRETTING AMPLITUDE MAP OF MARTENSITIC STAINLESS STEELS	**LAVELLA** / BOTTO	0054

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SESSION 5		**EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR**		
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09:50-10:10	SALA DE JUNTAS	MEASUREMENT OF HYSTERESIS LOOPS IN FRETTING WEAR	**FANTETTI** / SCHWINGSHACKL / NOWELL	0025
10:10-10:30	SALA DE JUNTAS	CHARACTERIZATION OF CONTACT ZONE AND WEAR IN FRETTING FATIGUE WITH A CONFOCAL MICROSCOPE	JORDANO / **NAVARRO** / VÁZQUEZ / DOMÍNGUEZ	0069
10:30-10:50	SALA DE JUNTAS	RUNNING-IN IN FRETTING, TRANSITION FROM NEAR STABLE FRICTION REGIME TO GROSS SLIDING	**HINTIKKA** / MÄNTYLÄ / VAARA / FRONDELIUS / LEHTOVAARA	0033

TIME	ROOM	TITLE	AUTHORS	CODE
PARALLEL SESSION 5		**THEORIES AND MECHANISMS OF FRETTING FATIGUE/WEAR**		
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09:50-10:10		MICRO-PILLAR ANALYSIS OF DEBRIS LAYER IN RELATION TO FRETTING WEAR RESPONSE OF HS25 COBALT-BASED SUPERALLOY AT HIGH TEMPERATURES	A VIAT / G. GUILLONNEAU / **S. FOUVRY** / G. KERMOUCHE / J. F. HENNE.	0046
10:10-10:30		WEAR MECHANISM OF FRETTED COMOCRSI COATINGS	**LAVELLA** / BOTTO	0053
10:30-10:50		CHARACTERIZATION OF THE FRETTING FATIGUE DAMAGE OF STAINLESS STEEL AT HIGH TEMPERATURE	**ATTIA**	0056
10:50-11:20	COFFEE BREAK			
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11:20-11:40	SALA DE JUNTAS	COMPARING THE PERFORMANCE OF PLASMA SPRAYED CU-NI-IN AND COCRALYSI – HBN COATINGS UNDER FRETTING WEAR CONDITIONS	**SEELAMANTHULA** / S / G	008
11:40-12:00		EFFECT OF SURFACE TREATMENT ON FRETTING FATIGUE STRENGTH OF PREMIUM THREADED CONNECTION	**OKU** / ANDO / SUGINO / HOSOI / TAKAZAKI / KUBOTA	0010
12:00-12:20		FRETTING WEAR AND FATIGUE BEHAVIORS OF BIAS-GRADED GRAPHITE-LIKE CARBON FILMS	**SHI** / LISKIEWICZ / BEAKE / CHEN / SUN	0011
12:20-12:40		AN EXPERIMENTAL INVESTIGATION OF THE ENDURANCE OF FRETTING PALLIATIVES	**BLADES** / PAYNTER / ANDRESEN / WORMSEN	0019
12:40-13:00		ROOM AND ELEVATED TEMPERATURE FRETTING WEAR BEHAVIOR OF PLASMA ELECTROLYTIC OXIDATION COATED TI6AL4V SAMPLES IN DIFFERENT ELECTROLYTE SOLUTIONS	**SINGH** / S / L / G	0026
PARALLEL SESSION 6		**MODELLING IN FRETTING FATIGUE/WEAR**		
11:20-11:40	SALÓN DE GRADOS	INFLUENCE OF FRETTING WEAR ON BLADED-DISKS DYNAMIC ANALYSIS	**LEMOINE** / NELIAS / THOUVEREZ / VINCENT	0022
11:40-12:00		WEAR NUMERICAL ASSESSMENT FOR PARTIAL SLIP FRETTING FATIGUE CONDITIONS	**ARAUJO CARDOSO** / DOCA / ALEXANDER ARAÚJO / POMMIER / NÉRON	0023
12:00-12:20		AN IDEALISED DESCRIPTION OF THE FRICTIONAL RECEDING CONTACT BEHAVIOUR OF A BOLTED JOINT SUBJECTED TO SHEAR LOADING	**DA PONTE LOPES** / HILLS	0024
12:20-12:40		PREDICTION OF CRACK PATHS USING THE MINIMUM SHEAR STRESS RANGE UNDER FRETTING CONDITIONS WITH INCOMPLETE CONTACT CONFIGURATION	INFANTE/GARCÍA / LLAVORI / ZABALA / **GINER**	0048
12:40-13:00		EFFECTS OF HYDROGEN POROSITIES ON FRETTING FATIGUE BEHAVIOUR OF ALUMINIUM ALSI10MG: A NUMERICAL STUDY	**TALEMI**	0028
13:00-14:30	LUNCH			

WEDNESDAY 3/4/2019

TIME	ROOM	TITLE	AUTHORS	CODE
SESSION 7		**MODELLING IN FRETTING FATIGUE/WEAR**		
09:30-09:50	SALÓN DE GRADOS	MODELLING OF FRETTING FATIGUE ENDURANCE FROM PARTIAL TO GROSS SLIP: EFFECT OF DEBRIS LAYER	**ARNAUD** / GARCIN / FOUVRY	0047
09:50-10:10		PREDICTION OF CONTACT CONDITION AND SURFACE DAMAGE BY SIMULATING VARIABLE FRICTION COEFFICIENT AND WEAR	**MÄNTYLÄ** / HINTIKKA / VAARA / FRONDELIUS / JUOKSUKANGAS / LEHTOVAARA	0027
10:10-10:30		ASSESSMENT OF FRETTING FATIGUE IN HIGH STRENGTH STEEL BOLTED CONNECTIONS WITH SIMPLIFIED FE MODELLING TECHNIQUES.	**VENUGOPAL POOVAKAUD**	0052
10:30-10:50	COFFEE BREAK			
SESSION 8		**MODELLING IN FRETTING FATIGUE/WEAR**		
10:50-11:20	SALÓN DE GRADOS	NUMERICAL SIMULATION OF CRACK NUCLEATION RISK UNDER FRETTING WEAR BY TAKING INTO ACCOUNT THE THIRD BODY LAYER	**GARCIN** / ARNAUD / FOUVRY	0055
11:20-11:40		THE GENERALIZED LOCAL MODEL (GLM) AS A METHODOLOGY TO ENHANCE RELIABILITY IN FRETTING FATIGUE LIFETIME PREDICTION	**MUÑIZ-CALVENTE** / VAZQUEZ / NAVARRO / ERENA / FERNANDEZ-CANTELI	0059
11:40-12:00		MODELLING FRETTING FATIGUE LIFE IN COMPLEX LOADING CONDITIONS	**ROUSSEAU**	0063
12:30	LUNCH			

ABSTRACTS

Code: 0046

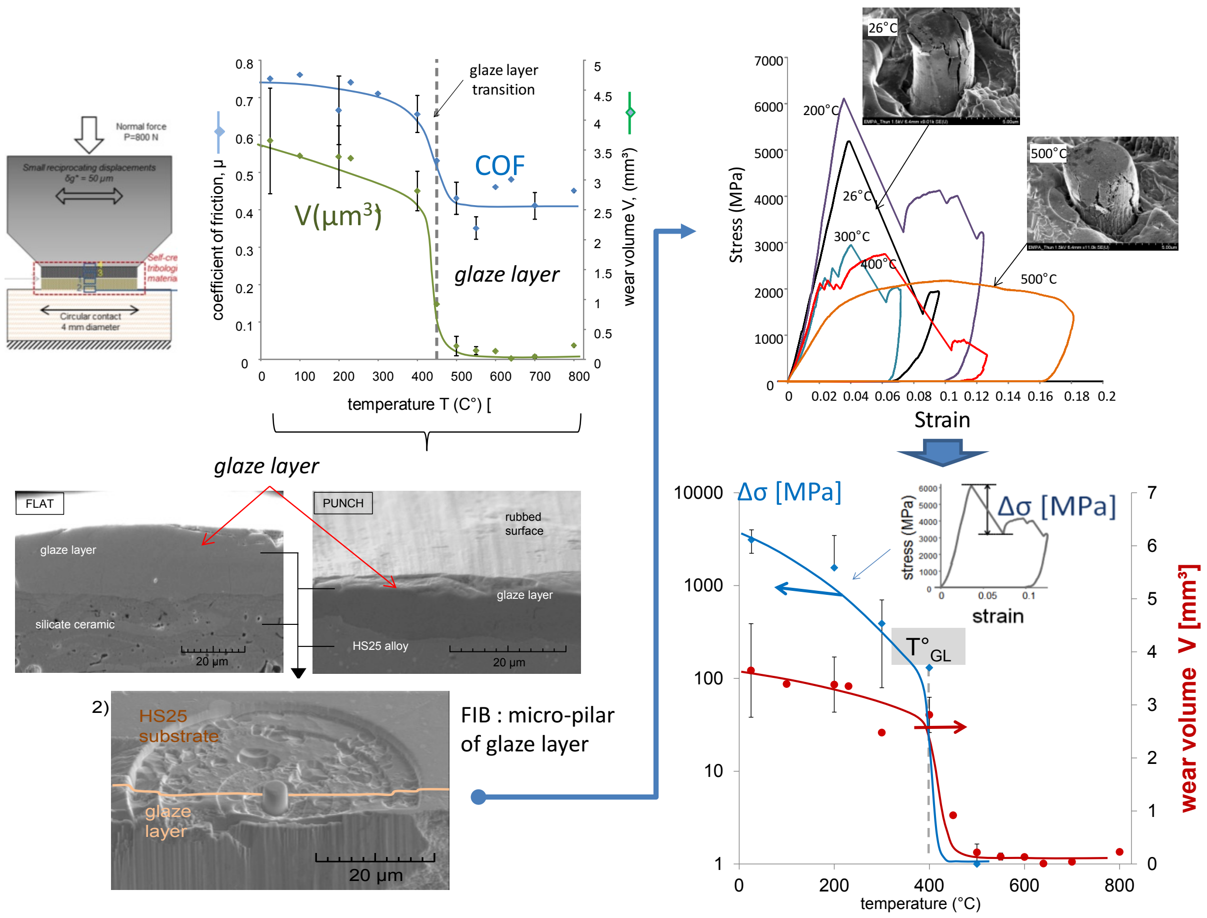

Figure 1: Illustration how the rheological properties of debris layer (quantified using high temperature micro pilar investigations) is explaining the transition from high wear rate T< T_{GL} (brittle properties of debris layer) to very low wear rate T>T_{GL} (ductile properties of debris layer).

9th Symposium on Fretting Fatigue SEVILLE april 1st to 3rd, 2019 ISFF9

Code: 0053

Wear mechanism of fretted CoMoCrSi coatings

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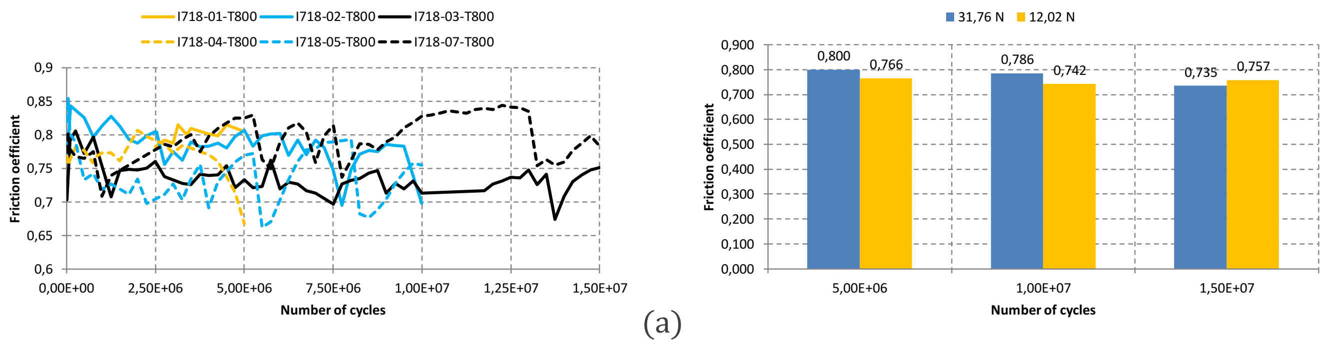
KEYWORDS. Fretting, wear, friction, CoMoCrSi coatings, T-800.

ABSTRACT. Coatings based on CoMoCrSi alloys are commonly applied on the damping surfaces of turbine blades, particularly in aero engines. The reason is the mitigation of the wear. If severe wear occur, the effectiveness of the damping effect could be decreased. Therefore, the vibration increase and the life of blade decrease. These mating surfaces are usually stressed with reciprocating relative displacement in dry condition with low amplitude. In other word, the damping surfaces are usually fretted. This study investigates the wear mechanism at the contact damping interfaces coated by Tribaloy® T-800.

The methodology was based on a wide experimental tests campaign performed with point contact test rig [1]. A peculiarity of this rig is that relative displacement measurements are not affected by the test rig compliance affects, [2],[3]. In other words, there is no difference between imposed and real displacement amplitude. Nine sets of experimental parameters was analyzed at three temperatures (Room Temperature, 600 and 800°C), two normal loads (12 and 32 N), three strokes (30, 60, 150 micrometers) and durations of 3, 5, 10, 15 M-cycles. Friction coefficient was computed using the hysteresis loops measured during the wear test. The worn surfaces were measured by optical instrument based on focus variation. Wear volumes were accurately computed with a procedure that takes in to account the roughness of the surfaces [4]. The wear groove was observed by scanning electron microscopy (SEM) at end of the test.

At RT the friction coefficient was substantially independent from the normal load, Figure 1. The wear rate at room temperature ware higher than at high temperature (600, 800 °C), Figure 2. The SEM observation of the worn surfaces reveals a morphology of the wear scar that was completely covered with brittle cracks in each sample. The damage propagation change from brittle (at RT) to ductile (at high temperature) and shows a different damage mechanism. In contrast with relation between wear volume and number of wear cycles, the relation between wear volume and energy dissipated was independent from normal load.

Code: 0053



(a) (b)

Figure 1: Friction coefficient measurements at room temperature, (a) instantaneous measurements during the fretting process; (b) average friction coefficient during the whole fretting process.

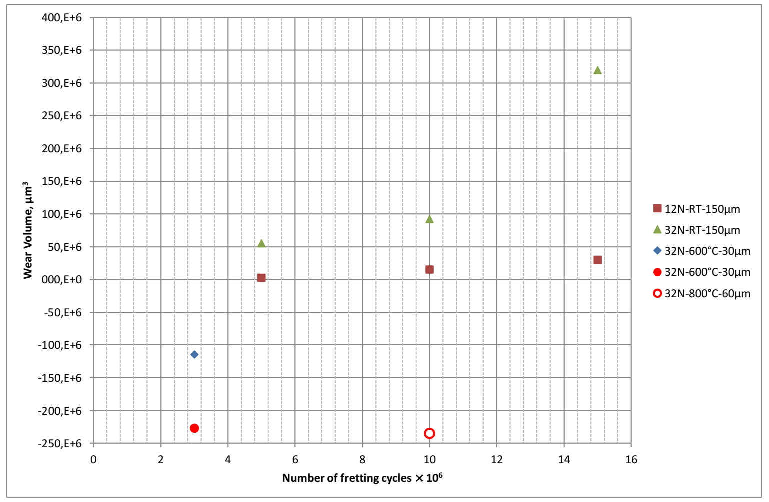


Figure 2: Wear volumes as a function of fretting cycles.

References

[1] Lavella, M., Botto, D., Fretting wear characterization by point contact of nickel superalloy interfaces, Wear 271 (2011) 1543–1551. DOI: 10.1016/J.wear.2011.01.064.

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Code: 0056

Characterization of the Fretting Fatigue Damage of Stainless Steel at High Temperature

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KEYWORDS. Fretting fatigue. Stainless steel. Steam environment. High temperature. Fractographic analysis

Abstract.

Fretting is the damage that occurs when two surfaces are in contact and subject to oscillatory tangential movement. This damage results in a deterioration of surface quality and frequently produces a substantial decrease in the fatigue strength of the material. The latter is mainly attributed to the addition of alternating frictional stresses, and the continuous destruction of the protective surface film. A comprehensive analysis of the fretting wear and fretting fatigue mechanisms, their dependence on various process parameters, and the test methods and equipment is given in references [1-3]. It has been recognized that fretting fatigue is a serious problem in steam turbines, which operate at elevated temperatures under increasingly severe conditions caused by higher demands in power and efficiency [4-7]. Fretting fatigue of stainless steels has been investigated by a number of researchers to establish of process variables on fretting life [8, 9] and to improve fatigue life through surface nanostructuring [10], plasma nitriding [11] and surface shot peening [12].

Tests were conducted to establish the plain- and fretting-fatigue S-N curves of stainless steel-403 in air at room temperature and in steam at 300oC. Analysis of the test results showed that the increase in the temperature and the presence of steam environment have insignificant effect on the plain fatigue S-N curve. Only 10% reduction in the fatigue strength has been observed. However, the presence of the fretting action, in superheated steam environment resulted in a significant drop in the fatigue strength by more than 70% due to acceleration in both mechanisms of crack initiation and crack propagation.

A fractographic analysis of the fracture surface in plain- and fretting-fatigue testing of stainless steel-403 has been analyzed to provide information regarding: (a) the state of stress that caused the material fracture, and (b) the crack origin, and the fracture sequencing and progress. Examination of the fretting wear damage indicated that a gross macro-slip occurred at the specimen/pad interface, resulting in delamination controlled fretting wear process. The fretting damage prompted also the formation of a network of secondary cracks that is oriented in a direction perpendicular to the direction of slip. In the course of this investigation, a special care has been taken in keeping the fracture surface undamaged, since the fretting debris may fall into the fatigue crack and may distort the fracture surface and mask the fatigue striations and the origin of the crack [13,14]. Wear of fracture surface may also produce debris and contact marks [15].

Code: 0063

The intensity factors of these reference spatial fields are hence a set of nonlocal variables which constitute the degrees of freedom of the problem. It is shown that a very small number of them is required to accurately describe the mechanical problem. The so-called "linear intensity factors" I characterize the elastic part of the field while the "complementary intensity factors" I^c characterize partial slip within the contact area. With these new variables, crack initiation thresholds, for different radii [3] or fatigue stresses (Fig.2 a-b), fall on the same curve.

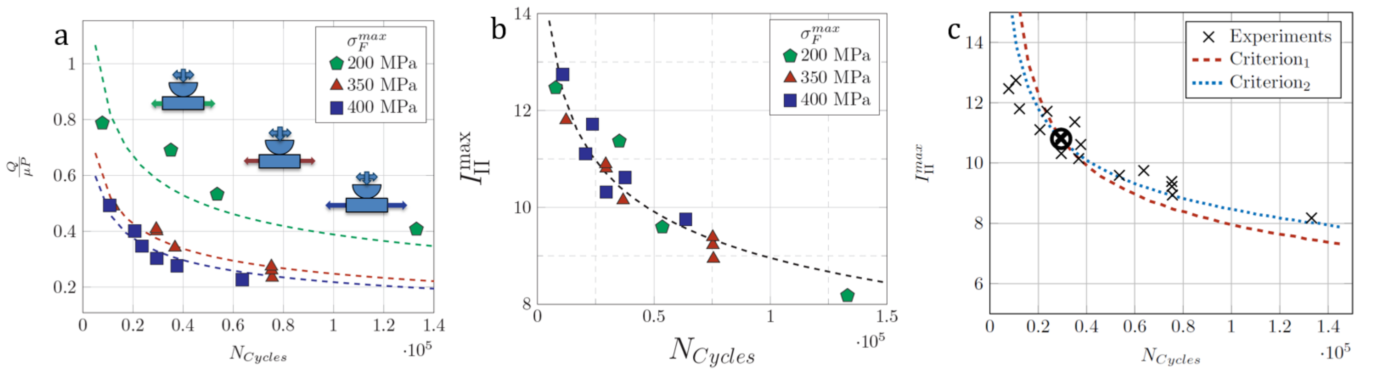

Figure 2: (a) Experimental Wöhler curve for fretting-fatigue crack initiation for TA6V [4]. (b) Nonlocal Wöhler curve using "linear intensity factors". (c) Nonlocal crack initiation boundary predicted by the criteria.

3D finite element analyses were conducted, first to build the framework of this approximation, second to qualify its accuracy and finally to determine the nonlinear response of a contact in multiaxial fretting-fatigue conditions.

An incremental constitutive model was developed to predict this nonlinear response and was compared to the results of the finite elements analyses.

Finally, these nonlocal intensity factors are used to set up crack initiation criteria based on the accumulation of the micro sliding $\left(\int_t |dI_{II}^c|\right)$ and on the energy dissipated by friction $\left(\int_t |I_{II} dI_{II}^c|\right)$. The predicted crack initiation threshold and fretting fatigue lives are compared to experimental data (Fig.2 c).

This nonlocal representation has the advantage of being independent of the geometry of the contacting bodies. So, intensity factors can be used to predict the behavior of real-scale industrial assembly using data obtained on laboratory test geometry.

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