

Fretting amplitude map of martensitic stainless steels

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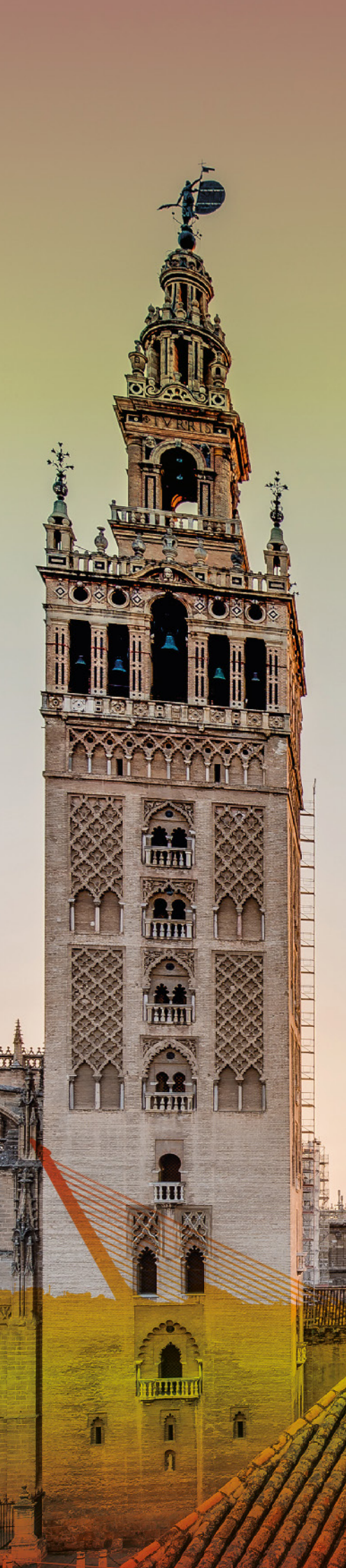
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# Book of Abstracts

9<sup>th</sup> Symposium on Fretting Fatigue

SEVILLE ISFF9  
april 1<sup>st</sup> to 3<sup>rd</sup>, 2019



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## Welcome

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Dear colleague,

It is a pleasure for me to invite you to participate in the **9<sup>th</sup> 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 field 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
SESSION 1		EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR		
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
PARALLEL SESSION 1		PALLIATIVES AGAINST FRETTING FATIGUE/WEAR		
09:30-09:50	SALÓN DE GRADOS	IMPROVEMENT OF FRETTING FATIGUE STRENGTH OF SPLINED SHAFT BY COMBINATION OF PRESS FITTING	KUBOTA / MIWA	0032
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
10:50-11:20	COFFEE BREAK			
SESSION 2		MODELLING IN FRETTING FATIGUE/WEAR		
11:20-11:40	SALA DE JUNTAS	A REVIEW OF PARTIAL SLIP SOLUTIONS FOR CONTACTS REPRESENTED BY HALF-PLANES	HILLS / ANDRESEN	004
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
<b>PARALLEL SESSION 2</b>		<b>EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR</b>		
11:20-11:40	SALÓN DE GRADOS	ANALYSIS OF COEFFICIENT OF FRICTION DERIVATION METHODS FOR FRETTING FATIGUE IN THIN STEEL WIRES	GARATE / ZABALA / GÓMEZ / AGINAGALDE / TATO / LLAVORI	0039
11:40-12:00		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		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		EFFECT OF VELOCITY ON THE IMPACT- SLIDING FRET- TING WEAR BEHAVIOR OF 304 STAINLESS STEEL	YIN / CAI / YU / PENG / ZHU	0050
13:00-14:30	LUNCH			
<b>SESSION 3</b>		<b>MODELLING IN FRETTING FATIGUE/WEAR</b>		
14:30-14:50	SALA DE JUNTAS	A MACHINE LEARNING APPROACH TO THE PREDIC- TION OF FRETTING FATIGUE LIFE	NOWELL	0014
14:50-15:10		NUMERICAL CORRELATION BETWEEN ACOUSTIC EMISSION AND FRETTING REGIME TRANSITION	WADE / CLARKE / COPLEY / AL SHEIKH OMAR / BRYANT / LISKIEWICZ	0017
15:10-15:30		INVESTIGATION OF EARLY CRACK ORIENTATION IN 7050-T7451 ALUMINUM ALLOY UNDER FRETTING CONDITIONS	ALMEIDA / CASTRO / ARAÚJO / CARDOSO	0020
15:30-15:50		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
<b>PARALLEL SESSION 3</b>		<b>APPLICATIONS AND CASE STUDIES</b>		
14:30-14:50	SALÓN DE GRADOS	EFFECT OF AMPLITUDE AND CURRENT DENSITY ON THE BENDING FRETTING FATIGUE LIFE OF INTEGRAL DROPPERS USED IN HIGH SPEED RAILWAY CATENARY SYSTEM	LIU / PENG / XUE / ZHANG / LIU / ZHU	0035
14:50-15:10		FRETTING IN NUCLEAR POWER SYSTEMS : A REVIEW	CAI / ZHU	0049
15:10-15:30		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
15:30-15:50		FRETTING FATIGUE ANALYSIS OF FULL-SCALE RAILWAY AXLE IN PRESENCE OF THE ARTIFICIAL MICRO-NOTCHES	POURHEIDAR	0064
16:10-16:40	COFFEE BREAK			



TIME	ROOM	TITLE	AUTHORS	CODE
<b>SESSION 4</b>		<b>MODELLING IN FRETTING FATIGUE/WEAR</b>		
16:40-17:00	SALA DE JUNTAS	AN EXPERIMENTAL AND NUMERICAL MULTI-SCALE APPROACH TO PREDICT THE FRETTING-FATIGUE LIFE OF OVERHEAD CONDUCTORS	JULIEN / SIMON / SIEGFRIED / CHRISTINE / FIKRI	0037
17:00-17:20		FRETTING FATIGUE UNDER VARIABLE AMPLITUDE LOADING, PART 1: NUMERICAL ANALYSIS	PINTO / ARAÚJO / TALEMI / CARDOSO	0038
17:20-17:40		CRYSTAL PLASTICITY FINITE ELEMENT MODELLING OF MICROSTRUCTURE EFFECTS IN FRETTING FATIGUE FOR FLEXIBLE MARINE RISERS	ASHTON / HARTE / O'HALLORAN / LEEN	0030
<b>PARALLEL SESSION 4</b>		<b>EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR</b>		
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		STUDY OF SIZE EFFECTS IN FRETTING FATIGUE	ARAUJO	0061
17:20-17:40		FRETTING AMPLITUDE MAP OF MARTENSITIC STAINLESS STEELS	LAVELLA / BOTTO	0054

**TUESDAY 2/4/2019**

TIME	ROOM	TITLE	AUTHORS	CODE
09:00-09:30	SALÓN DE GRADOS	SURFACE DESIGN AGAINST THIRD BODY FRET- TING-CORROSION OF ELECTRICAL CONNECTORS	TOMASZ LISKIEWICZ	0066
<b>SESSION 5</b>		<b>EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR</b>		
09:30-09:50	SALA DE JUNTAS	AN EXPERIMENTAL INVESTIGATION OF THE FRETTING FATIGUE STRENGTH UNDER CONDITIONS OF VARYING NORMAL LOAD	BLADES / PAYNTER / ANDRE- SEN / WORMSEN	0018
09:50-10:10		MEASUREMENT OF HYSTERESIS LOOPS IN FRETTING WEAR	FANTETTI / SCHWINGSACKL / NOWELL	0025
10:10-10:30		CHARACTERIZATION OF CONTACT ZONE AND WEAR IN FRETTING FATIGUE WITH A CONFOCAL MICROSCOPE	JORDANO / NAVARRO / VÁZ- QUEZ / DOMÍNGUEZ	0069
10:30-10:50		RUNNING-IN IN FRETTING, TRANSITION FROM NEAR STABLE FRICTION REGIME TO GROSS SLIDING	HINTIKKA / MÄNTYLÄ / VAARA / FRONDELIUS / LEHTOVAARA	0033



TIME	ROOM	TITLE	AUTHORS	CODE
<b>PARALLEL SESSION 5</b>		<b>THEORIES AND MECHANISMS OF FRETTING FATIGUE/WEAR</b>		
09:30-09:50	SALÓN DE GRADOS	ROLE OF OXIDE FILM ON THE FRETTING WEAR RESISTANCE OF A NUCLEAR FUEL ROD	LEE / KIM / KIM	0013
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			
<b>SESSION 6</b>		<b>PALLIATIVES AGAINST FRETTING FATIGUE/WEAR</b>		
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
<b>PARALLEL SESSION 6</b>		<b>MODELLING IN FRETTING FATIGUE/WEAR</b>		
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 ALS10MG: A NUMERICAL STUDY	TALEMI	0028
13:00-14:30	LUNCH			



WEDNESDAY 3/4/2019				
TIME	ROOM	TITLE	AUTHORS	CODE
<b>SESSION 7</b>		<b>MODELLING IN FRETTING FATIGUE/WEAR</b>		
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			
<b>SESSION 8</b>		<b>MODELLING IN FRETTING FATIGUE/WEAR</b>		
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			



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# ABSTRACTS



Code: 0054

## Fretting amplitude map of martensitic stainless steels

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**KEYWORDS.** Fretting regime, sliding amplitude, martensitic stainless steels, X20Cr13, M152.

**ABSTRACT.** On the basis of well-known dependence fretting process from the sliding amplitude [1], experiments was performed in order to verify the dependence of fretting process upon the slip amplitude. The reason is that the dependence of the fretting process from the sliding amplitude has been critically reviewed [2], [3]. One of the main critical point was that [1] did not consider the difference between the real displacement amplitude and the imposed amplitude due to compliances of the test rigs. The experimental data used for the considerations reported in [1] were actually based on the imposed displacement amplitude instead to the real sliding amplitude.

Fretting tests were performed by means of the high precision test rig[4]. The main peculiarities of this test rig are: flat on flat contact with free approaching of contact surfaces; displacement control; contact force and relative displacement measured continuously for each hysteresis loop; working temperature from Room Temperature (RT) to more than 1000 °C. The relative displacement are measured and very near to the contact interfaces, substantially there is no difference between the imposed sliding amplitude and the applied amplitude, about the importance of imposed and applied sliding amplitude[5], [3]. In other words, there are no effect of test rig compliance on the displacement measurements. Moreover, because of the free approaching and the fixture specimen's characteristic, the test rig allows the disassembling and subsequent re-assembling with a negligible impact on the fretting process. Disassembling – assembling operations are necessary to measure the 3D profile of the worn surfaces and to determine the wear volume. A great advantage of this rig is that wear volume measurements can be done on the same couple of specimens at different stage of the fretting process. Experiments were performed at Room Temperature (RT), two contact pressure (15, 25 MPa), four strokes (10, 15, 20, 50 micrometres), two martensitic stainless steels (X20Cr13, M152) and different durations from 15 to 160 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 [6]. The wear groove was observed by scanning electron microscopy (SEM) at end of the test.



Code: 0054

Figure 1 illustrate a fretting amplitude maps. In general, the evolution of wear volume as a function of the amplitude proposed in [1] seems to be confirmed in the gross slip regime. On the other hand the same wear volume evolution proposed for the mixed stick-slip and stick regimes require a more in depth discussion.

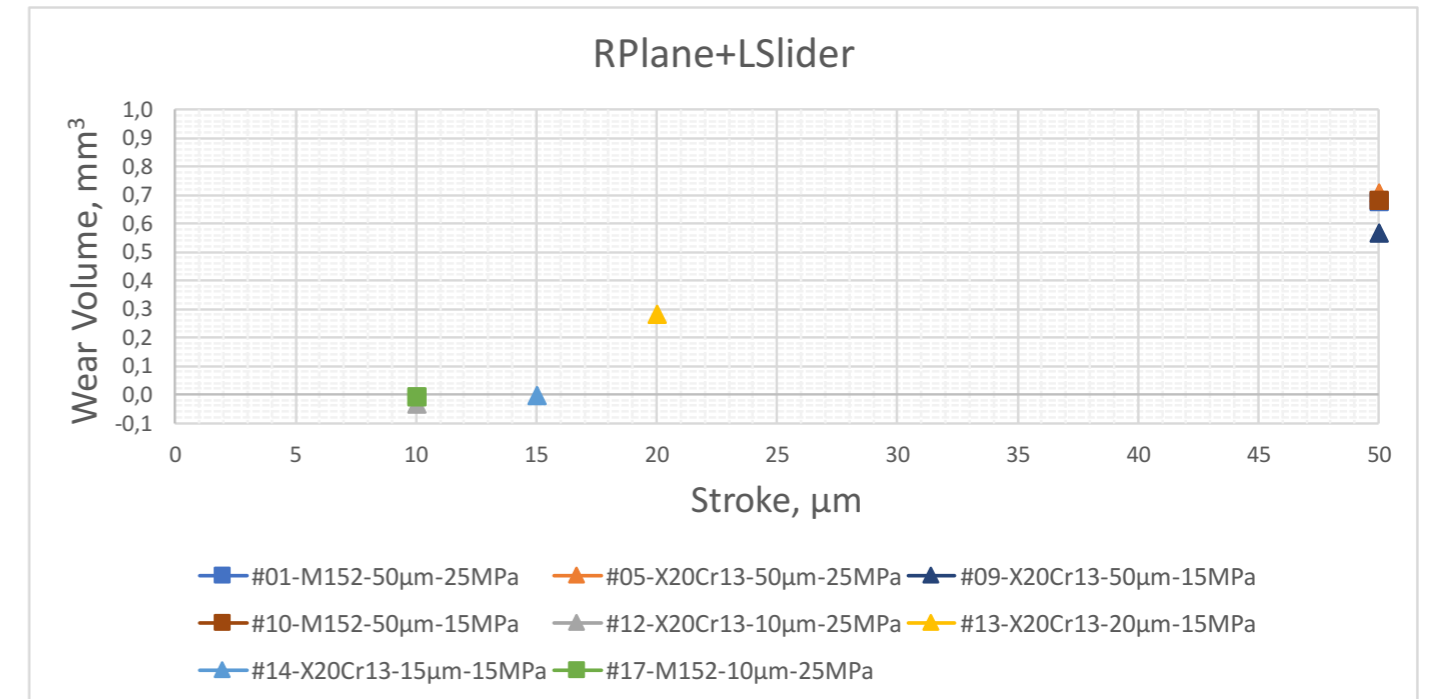


Figure 1: Wear volumes as a function of fretting cycles.

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- [5] Fouvry, S., Kapsa, P., Vincent, L., Analysis of sliding behavior for fretting loadings: determination of transaction criteria, *Wear* 185 (1995) 35-46.
- [6] Lavella, M., Contact Properties and Wear Behaviour of Nickel Based Superalloy René 80, *Metals* 6 (7) (2016) 159, DOI: 10.3390/met6070159.



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.

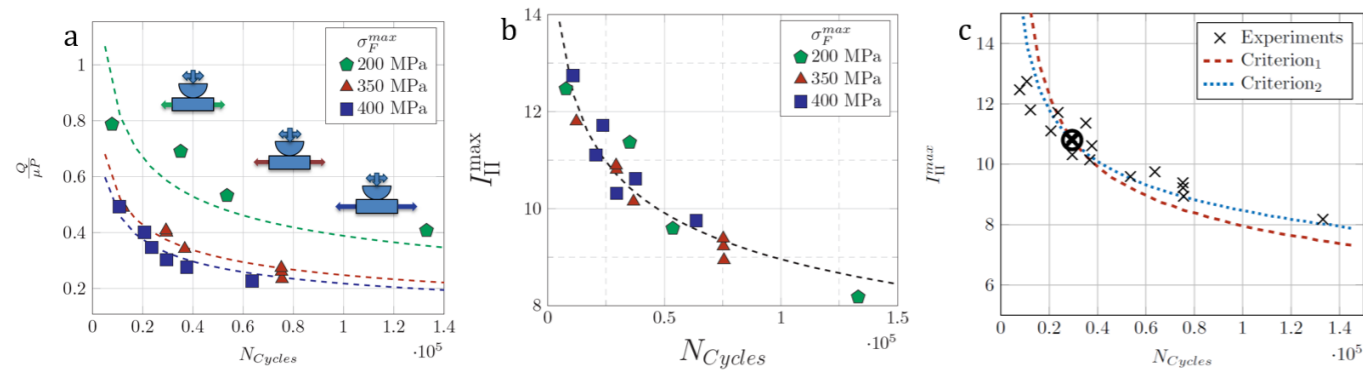


Figure 2: (a) Experimental Wöhler curve for fretting-fatigue crack initiation for TA6V [4]. (b) Nonlocal Wöhler curve using “linear intensity factors”. (c) Nonlocal crack initiation boundary predicted by the criteria.

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 ( $\int_t dI_{II}^c$ ) and on the energy dissipated by friction ( $\int_t |I_{II} dI_{II}^c|$ ). 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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