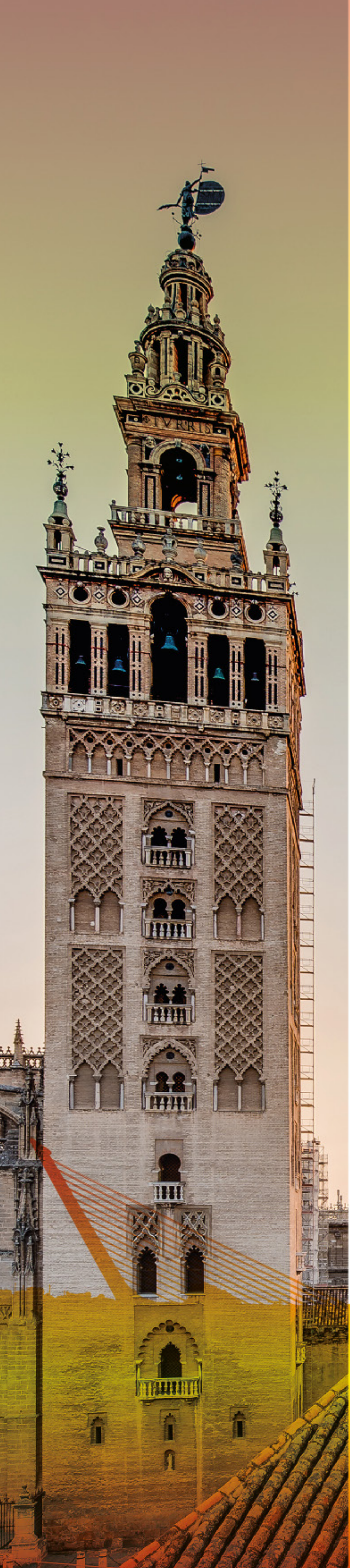
Wear mechanism of fretted CoMoCrSi coatings

Original
Wear mechanism of fretted CoMoCrSi coatings / Lavella, M.; Botto, D.. - ELETTRONICO. - (2019), pp. 85-86. (Intervento presentato al convegno 9th Symposium on Fretting Fatigue ISFF9 tenutosi a Seville nel April 1st - 3st, 2019).

Publisher:
www.isff9.org

Published
DOI:



Book of Abstracts

9th Symposium on Fretting Fatigue

ISFF9

SEVILLE
april 1st to 3rd, 2019

UNIVERSIDAD DE SEVILLA

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 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.

COMMITTEES

INTERNATIONAL SCIENTIFIC COMMITTEE

America

- Prof. J.A.Araújo (Brazil)
- Prof. R.W.Neu (USA)

Europe

- Prof. J.Dominguez (Spain)
- Prof. S. Fouvry (France)
- Prof. T.Liskiewicz (UK)
- Prof. D.Nowell (UK)
- Prof.P.Shipway (UK)

Asia

- Prof. H-K.Kim (Korea)
- Prof. M.Kubota (Japan)
- Prof. M.N.H.Murthy (India)
- Prof. M.H.Zhu (China)

Chairman

- Prof. Jesús Vázquez Valeo (Spain)

Co-Chairmen:

- David Hills (UK)
- David Hoeppner (USA)
- Helmi Attia (Canada)
- Toshio Hattori (Japan)
- Trevor Lindley (UK)
- Yoshiharu Mutoh (Japan)
- Min-Hao Zhu (China)

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
PARALLEL SESSION 2		**EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR**		
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 FRETTING WEAR BEHAVIOR OF 304 STAINLESS STEEL	YIN / **CAI** / YU / PENG / ZHU	0050
13:00-14:30	LUNCH			
SESSION 3		**MODELLING IN FRETTING FATIGUE/WEAR**		
14:30-14:50	SALA DE JUNTAS	A MACHINE LEARNING APPROACH TO THE PREDICTION 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
PARALLEL SESSION 3		**APPLICATIONS AND CASE STUDIES**		
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
SESSION 4		**MODELLING IN FRETTING FATIGUE/WEAR**		
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
PARALLEL SESSION 4		**EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR**		
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 FRETTING-CORROSION OF ELECTRICAL CONNECTORS	**TOMASZ LISKIEWICZ**	0066
SESSION 5		**EXPERIMENTAL RESULTS IN FRETTING FATIGUE/WEAR**		
09:30-09:50	SALA DE JUNTAS	AN EXPERIMENTAL INVESTIGATION OF THE FRETTING FATIGUE STRENGTH UNDER CONDITIONS OF VARYING NORMAL LOAD	**BLADES** / PAYNTER / ANDRESEN / WORMSEN	0018
09:50-10:10		MEASUREMENT OF HYSTERESIS LOOPS IN FRETTING WEAR	**FANTETTI** / SCHWINGSHACKL / NOWELL	0025
10:10-10:30		CHARACTERIZATION OF CONTACT ZONE AND WEAR IN FRETTING FATIGUE WITH A CONFOCAL MICROSCOPE	JORDANO / **NAVARRO** / VÁZQUEZ / 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
PARALLEL SESSION 5		**THEORIES AND MECHANISMS OF FRETTING FATIGUE/WEAR**		
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		
SESSION 6		**PALLIATIVES AGAINST FRETTING FATIGUE/WEAR**		
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

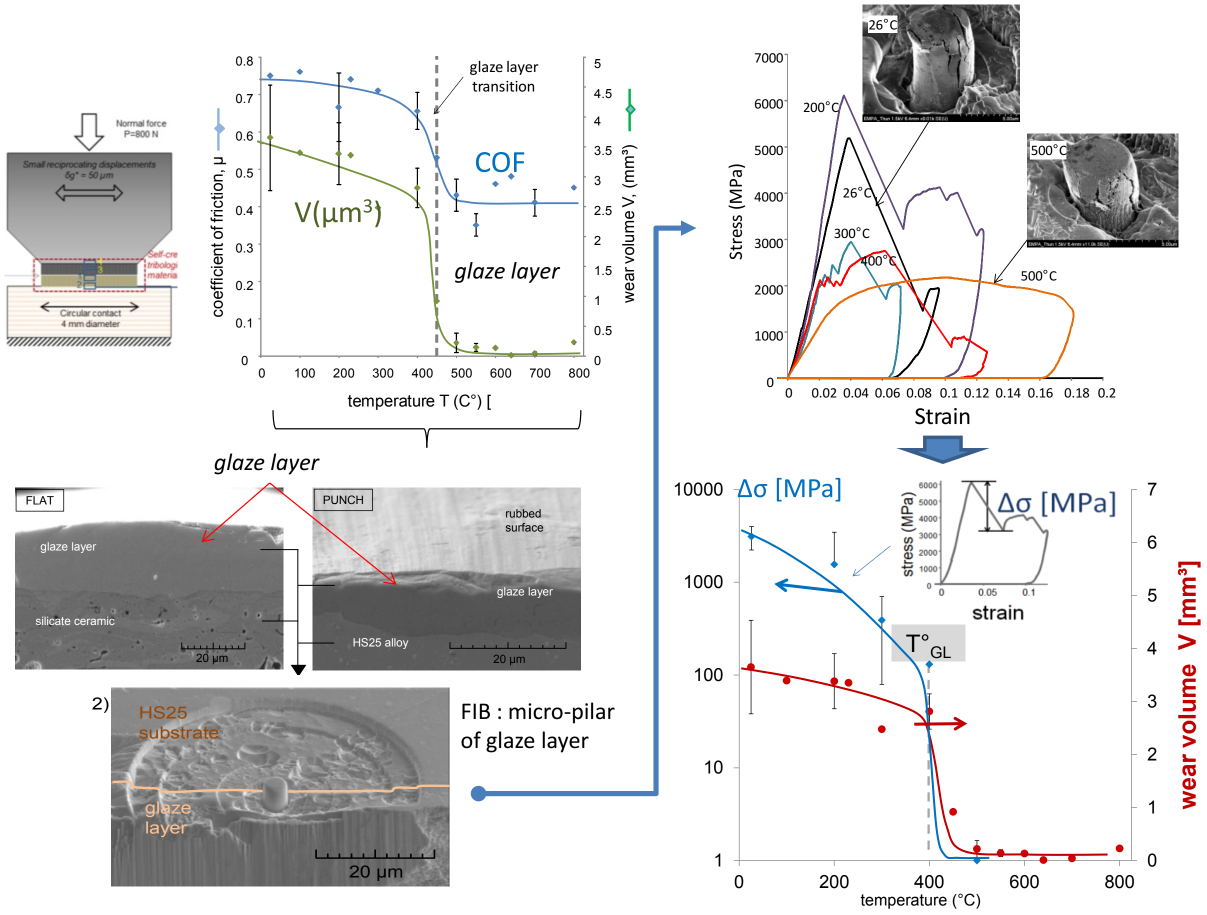


Figure 1: Illustration how the rheological properties of debris layer (quantified using high temperature micro pilar investigations) is explaining the transition from high wear rate T< T_{GL} (brittle properties of debris layer) to very low wear rate T>T_{GL} (ductile properties of debris layer).

Code: 0053

Wear mechanism of fretted CoMoCrSi coatings

M. Lavella
Department of Mechanical and Aerospace Engineering, Politecnico di Torino Corso Duca degli Abruzzi, 24-10129 Torino – Italy
mario.lavella@polito.it

D. Botto
Department of Mechanical and Aerospace Engineering, Politecnico di Torino Corso Duca degli Abruzzi, 24-10129 Torino – Italy
daniele.botto@polito.it

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.

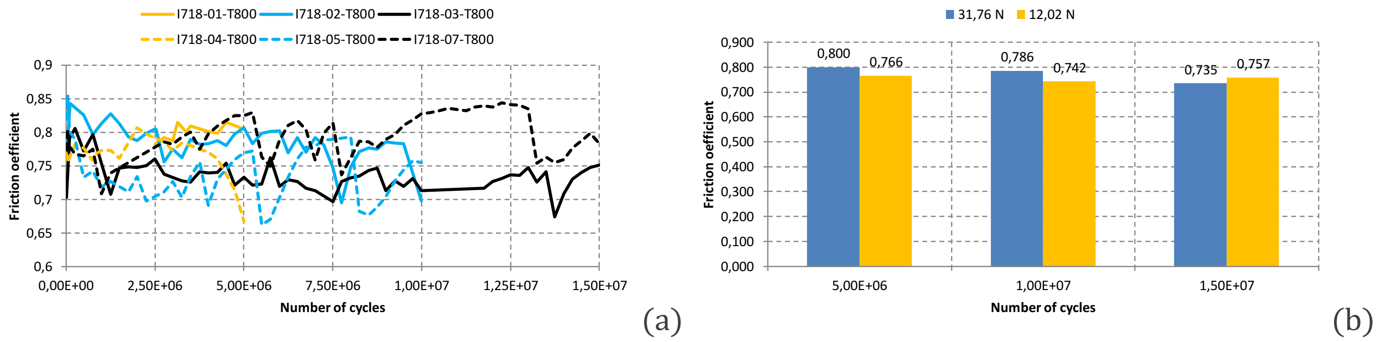


Figure 1: Friction coefficient measurements at room temperature, (a) instantaneous measurements during the fretting process; (b) average friction coefficient during the whole fretting process.

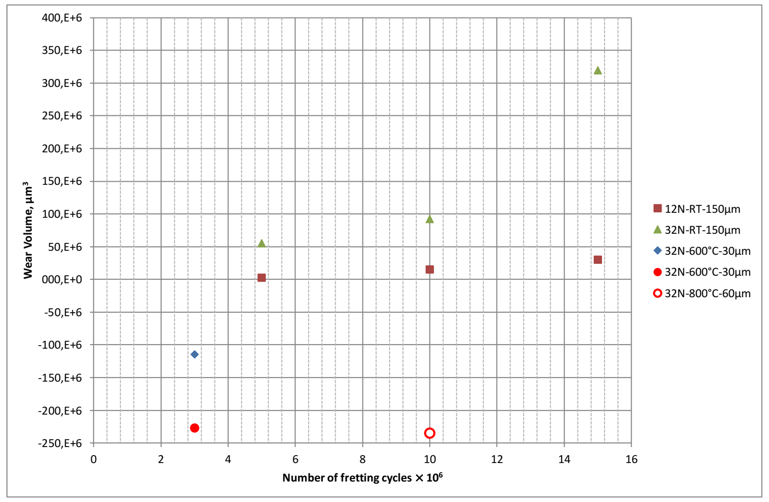


Figure 2: Wear volumes as a function of fretting cycles.

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.

[2] Fouvry, S., Kapsa, P., Vincent, L., Analysis of sliding behavior for fretting loadings: determination of transaction criteria, Wear 185 (1995) 35-46.

[3] Pearson, S.R., Shipway, P.H., Is the wear coefficient dependent upon slip amplitude in fretting? Vingsbo and Söderberg revisited, Wear 330-331 (2015) 93-102.

[4] Lavella, M., Contact Properties and Wear Behaviour of Nickel Based Superalloy René 80, Metals 6 (7) (2016) 159, DOI: 10.3390/met6070159.

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

M. Helmi Attia
Mechanical Engineering Department, McGill University
Aerospace Manufacturing Technology Centre, National Research Council Canada
Montreal, QC, Canada
helmi.attia@mcgill.ca

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.

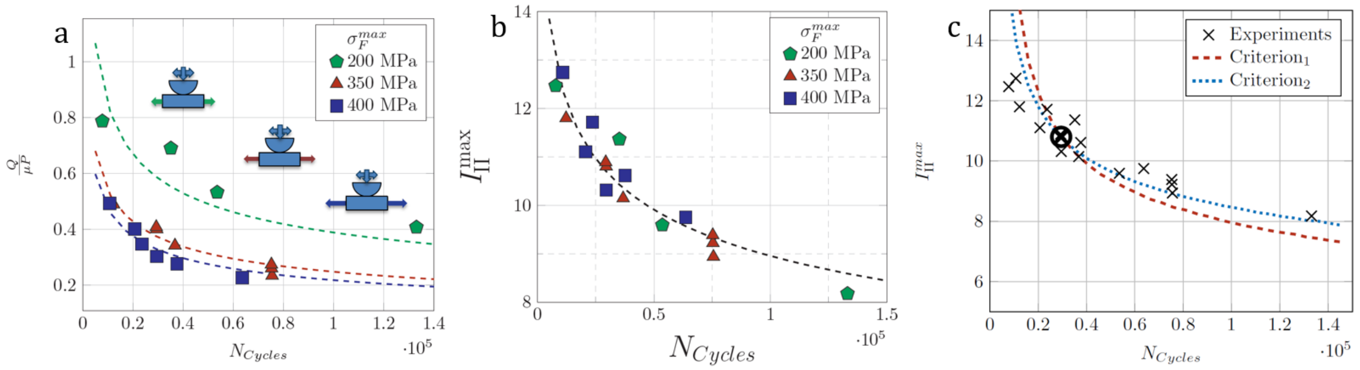


Figure 2: (a) Experimental Wöhler curve for fretting-fatigue crack initiation for TA6V [4]. (b) Nonlocal Wöhler curve using “linear intensity factors”. (c) Nonlocal crack initiation boundary predicted by the criteria.

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.

REFERENCES

[1] R. Amargier, S Fouvry, L Chambon, C Schwob, C Poupon. Stress gradient effect on crack initiation in fretting using a multiaxial fatigue framework. Int J Fatigue **32**:1904–12 (2010).

[2] M. Loève, Probability Theory I, Vol. 45 of Graduate Texts in Mathematics, Springer New York, New York, NY, 1977.

[3] C. Montebello, S Pommier, K Demmou, J Leroux, J Meriaux. Analysis of the stress gradient effect in fretting-fatigue through nonlocal intensity factors. Int. J. Fatigue, vol. 82, Elsevier; , p. 188–98.

[4] J. Meriaux. Etude expérimentale de modélisation de l’endommagement d’un contact aube disque de soufflante soumis à des chargements de fretting fatigue. 2010.

INDEX OF AUTHORS

NAME	ABSTRACTS
ABBASI, FARSHAD	0002, 0003
AGINAGALDE, ANDREA	0039
AL SHEIKH OMAR, ALAAEDDIN	0017
ALEXANDER ARAÚJO, JOSÉ	0023
ALMEIDA, GABRIEL	0020
ANDO, YOSHINORI	0010
ANDRADE PIRES, FRANCISCO	0029
ANDRESEN, HENDRIK	0004, 0018, 0019
ARAUJO, JOSÉ ALEXANDER	0061
ARAÚJO, JOSÉ	0020, 0021
ARAÚJO, JOSÉ ALEXANDER	0038
ARAUJO CARDOSO, RAPHAEL	0023
ARNAUD, PIERRE	0047, 0055
ASHTON, PATRICK	0030
ATTIA, HELMI	0057
ATTIA, HELMI	0001, 0056
BEAKE, BEN	0011
BERTO, FILIPPO	0034
BEYER, THIBAULT	0012
BLADES, LUKE	0018, 0019
BOEV, E.V.	0043
BOTTO, DANIELE	0053, 0054
BRAGOV, A.M.	0041, 0045
BRYANT, MICHAEL	0017
CAI, ZHENBING	0006, 0049, 0050, 0051
CARDOSO, RAPHAEL	0020
CARDOSO, RAPHAEL ARAÚJO	0038

NAME	ABSTRACTS
CARPINTERI, ANDREA	0007
CASTRO, FABIO	0020
CASTRO, FÁBIO	0021
CHAISE, THIBAUT	0012
CHEN, JIAN	0011
CHRISTINE, YANG	0037
CLARKE, BENJAMIN	0017
CONNAIRE, A.D.	0065
COPLEY, ROYCE	0017
DA PONTE LOPES, JHONATAN	0024
DE PANNEMAECKER, A. ALIX	001
DIAZ, JOSÉ	0021
DOCA, THIAGO	0023, 0029
DOMÍNGUEZ, JAIME	0058
DOMÍNGUEZ, J.	0068, 0069, 0070
ENDRINO, JOSÉ LUIS	0040
ERENA, DIEGO	0059, 0068
FANTETTI, ALFREDO	0025
FERNANDEZ-CANTELI, ALFONSO	0059
FERNÁNDEZ-CANTELI, ALFONSO	0058
FERREIRA, JORGE	0021
FIKRI, HAFID	0037
FOUVRY, SIEGFRIED	0046, 0047, 0055
FRONDELIUS, TERO	0027, 0033, 0042
G, SIVAKUMAR	0008
G, SUNDARARAJAN	0026
GARATE, IÑAKI	0039
GARCIN, SIMON	0047, 0055

NAME	ABSTRACTS
GARY, WILLIAMS	0001
GINER, EUGENIO	0040, 0048
GOEL, SAURAV	0040
GÓMEZ, XABIER	0039
GRIGORYEV, M. V.	0044
GUILLONNEAU, GAYLORD	0046
HAN, EN-HOU	0031
HARTE, ANNETTE	0030
HARTE, A.M.	0065
HAUGEN, BJØRN	0034
HE, JIFAN	0051
HENNE, JEAN-FRANÇOIS	0046
HELMI, ATTIA	0001
HILLS, DAVID	0004, 0024
HINTIKKA, JOUKO	0027, 0033, 0042
HONKANEN, MARI	0042
HOSOI, SUZUKO	0010
IGUMNOV, L. A.	0041, 0044
IGUMNOV, L. A.	0043
INFANTE-GARCIA, DIEGO	0040
INFANTE-GARCÍA, DIEGO	0048
JORDANO, G.	0069
JULIEN, SAID	0037
JUOKSUKANGAS, JANNE	0027, 0042
KERMOUCHE, GUILLAUME	0046
KIM, HYUNG-KYU	0013
KIM, HYUN-GIL	0013
KORASHY, AHMED	0057

NAME	ABSTRACTS
KUBIAK, K.J.	0066
KUBOTA, MASANOBU	0010
KUBOTA, MASATONOBU	0032
L, RAMA KRISHNA	0026
LAMZIN, D. A.	0045
LAVELLA, MARIO	0053, 0054
LEE, YOUNG-HO	0013
LEEN, SEAN	0030, 0065
LEHTOVAARA, ARTO	0027, 0033, 0042
LEMOINE, ETIENNE	0022
LEROUX, JULIEN	0012
LISKIEWICZ, TOMASZ	0011, 0017, 0066
LITVINCHUK, S.YU.	0043, 0044, 0045
LIU, XINGCHEN	0031
LIU, XIYANG	0035
LIU, JIANHUA	0035
LLAVORI, IÑIGO	0039, 0040
LLAVORI, ÍÑIGO	0048
LOMUNOV, A. K.	0041, 0044, 0045
MAJZOOBI, GHOLAM HOSSEIN	0002, 0003
MÄNTYLÄ, ANTTI	0027, 0033, 0042
MARTÍN RODRÍGUEZ, VICENTE	0070
MING, HONGLIANG	0031
MIWA, MASATO	0032
MUNIZ-CALVENTE, MIGUEL	0058, 0059
NAVARRO, CARLOS	0058, 0059, 0069
NAVARRO, C.	0068, 0070
NELIAS, DANIEL	0012, 0022

NAME	ABSTRACTS
NÉRON, DAVID	0023
NOWELL, DAVID	0014, 0025
NURMI, VERNER	0042
O'HALLORAN, SINEAD	0030
O'HALLORAN, S. M.	0065
OKU, YOSUKE	0010
OSKOOEI, SAEID	0057
PANDIM, THIAGO	0029
PAYNTER, ROBERT	0018, 0019
PENG, JINFANG	0006, 0035, 0050, 0051
PINTO, ANDRÉ LUIS	0038
POMMIER, SYLVIE	0023
POURHEIDAR, AMIR	0064
REN, YANPING	0051
ROCHA, PEDRO	0021
ROUSSEAU, GUILLAUME	0063
RUSIN, E. E.	0041, 0045
S, GANESH SUNDARA RAMAN	0008, 0026
SCHWINGSHACKL, CHRISTOPH	0025
SEELAMANTHULA, ABHINAY	0008
SHI, XIANGRU	0011
SHIPWAY, PHILIP HOWARD	0067
SIEGFRIED, FOUVRY	0037, 0046
SILVA, COSME	0021
SIMON, GARCIN	0037
SINGH, KAMINI	0026
SUGINO, MASAAKI	0010
SUN, ZHENGMING	0011
SUNDE, STEFFEN LOEN	0034
TAKAZAKI, DAISUKE	0010
TALEMI, REZA	0028, 0038
TATO, WILSON	0039
THOMSON, VINCE	0057
THOUVEREZ, FABRICE	0022
VAARA, JOONA	0027, 0033, 0042
VANTADORI, SABRINA	0007
VAZQUEZ, JESUS	0059
VÁZQUEZ, JESÚS	0058
VÁZQUEZ, J.	0068, 0069, 0070
VENUGOPAL POOVAKAUD, VISHNU	0052
VIAT, ARIANE	0046
VINCENT, CAROLINE	0022
VIPPOLA, MINNAMARI	0042
VOLKOV, I. A.	0043, 0044
WADE, ABIGAIL	0017
WANG, BOTONG	0006
WANG, JIANQIU	0031
WEN, JIANGUO	0006
WORMSEN, ANDERS	0018, 0019
XU, ZHIBIAO	0006
XUE, BOKAI	0035
YIN, MEIGUI	0050
YU, YANQING	0050
ZABALA, ALAITZ	0039, 0040, 0048
ZANICHELLI, ANDREA	0007
ZHANG, ZHIMING	0031
ZHANG, JUN	0035
ZHU, MINHAO	0006, 0035, 0049, 0050, 0051
KONSTANTINOV, A. YU.	0041, 0043

INDEX OF KEYWORDS

KEYWORD	ABSTRACT
7050-T7451 ALUMINUM ALLOY	0020
ACCELERATED TESTING	001
ACRYLONITRILE BUTADIENE STYRENE	0029
ADDITIVE MANUFACTUERING	0028
ADHESION	0042
AL7075 ALUMINIUM ALLOY	007
ALLOY 690	0031
ALSI10MG	0028
ALUMINIUM	0037
ALUMINIUM ALLOY	0046
ALUMINUM WIRE	0021
AMPLITUDE	0035
ARTIFICIAL NEURAL NETWORK	0014
AXISYMMETRIC	0024
BENDING FRETTING FATIGUE(BFF)	0035
BIAS-GRADED	0011
BOLTED CONNECTION	0052
BOLTED JOINTS	0024
COMOCRSI COATINGS	0053
CONTACT MECHANICS	004
CONTACT STIFFNESS	0025
COPPER PLATING	0010
CORRELATION	0017

KEYWORD	ABSTRACT
CRACK INITIATION	0021, 0052
CRACK NUCLEATION	0037, 0055
CRACK ORIENTATION	0020
CRACK PATH	007
CRACK PROPAGATION	0046, 0048
CRACKS	0042
CRITICAL PLANE	0020
CRYSTAL PLASTICITY	0030
CRYSTALLOGRAPHIC TEXTURE	0030
CU-NI-IN	008
CURRENT INTENSITY	0035
CYCLIC LOADING	0018
DAMAGE	0042
DAMAGE MECHANICS	0012
DAMAGE MECHANISM	006, 0035
DISPLACEMENT	0031
ECOF	0039
EIM	0012
ELECTRON MICROSCOPY	0057
ELEVATED TEMPERATURE FRETTING BEHAVIOR	0026
ENDURANCE	0019
ESHELBY'S INCLUSION METHOD	0012
FATIGUE	0037

KEYWORD	ABSTRACT
FATIGUE LIFE	0011
FEA	0037
FEM SIMULATION	0047
FINITE ELEMENT ANALYSIS	0040
FINITE ELEMENT METHOD	0027
FLAT AND ROUNDED CONTACTS	0019
FLOW-INDUCED VIBRATION	0049
FRACTOGRAPHIC ANALYSIS	0056
FRETTING	0020, 0022, 0027, 0030, 0033, 0037, 0042, 0046, 0053, 0057
FRETTING CORROSION	0031, 0049
FRETTING DAMAGE	006
FRETTING FATIGUE	007, 0010, 0014, 0021, 0023, 0024, 0028, 0032, 0034, 0038, 0039, 0040, 0047, 0049, 0052, 0056
FRETTING FATIGUE EXPERIMENT	0018
FRETTING PROBABILISTIC APPROACH	0059
FRETTING REGIME	0017, 0054
FRETTING WEAR	001, 008, 0011, 0025, 0026, 0029, 0047, 0049, 0055
FRICTION	0027, 0033, 0053
FRICTION COEFFICIENT	008, 0025
FRICTION DERIVATION	0039

KEYWORD	ABSTRACT
FUEL ROD	0013
GAUSSIAN	001
GENERALIZED LOCAL MODEL	0059
GICOF	0039
GRAPHITE-LIKE CARBON FILMS	0011
GREASED AND COATED CONTACTS	0019
GRID-TO-ROD FRETTING	0013
HALF-PLANE THEORY	004
HARMONIC BALANCE METHOD	0022
HIGH TEMPERATURE	0056, 0057
HSS	0052
HYSTERESIS LOOPS	0025
IMPACT VELOCITY	0050
IMPACT- SLIDING FRETTING WEAR	0050
INCOMPLETE CONTACT	0048
INDUSTRIAL INITIATIVE	0034
INTEGRAL DROPPERS	0035
LIFE PREDICTION	0021
LIFETIME	007
LIFETIME PREDICTION	0047
LIFETIME WEIBULL FIELD	0059
M152	0054
MACHINE LEARNING	0014

KEYWORD	ABSTRACT
MANGANESE PHOSPHATE	0010
MARTENSITIC STAINLESS STEELS	0054
METAL-MATRIX COMPOSITE	0046
METALS	0028
MICRO-CRACK	006
MICROSCOPY	0042
MICROSTRUCTURE	0046
MULTIAXIAL FATIGUE	0020, 0023, 0038
NON-COULOMB FRICTION	0033
NON-FERROUS METALS	0057
NONLINEAR FORCED RESPONSE	0022
NORMAL FORCE	0031
NUCLEAR POWER PLANT	0049
NUMERICAL METHOD	0017
NUMERICAL MODELLING	0028
OFFSHORE STEEL	0029
ORIENTATION CRITERIA	0048
OVERHEAD CONDUCTOR	0021
OXIDE THICKNESS	0013
PARTIAL SLIP	004
PLAIN FATIGUE	0018
PLASMA ELECTROLYTIC OXIDATION	0026
PLASMA SPRAYED COATING	008

KEYWORD	ABSTRACT
POLYCARBONATE	0029
PRESS FITTING	0032
RANDOM VIBRATION	001
RECEDING CONTACTS	0024
RING DISLOCATIONS	0024
SAM	0012
SCALE AND SHAPE EFFECT	0059
SEMI-ANALYTIC CONTACT SIMULATION	0055
SEMI-ANALYTICAL METHOD	0012, 0022
SLIDING AMPLITUDE	0054
SLIDING VELOCITY	0050
SPACER GRID	0013
SPLINE	0032
STAINLESS STEEL	0056
STEAM ENVIRONMENT	0056
STRAIN-GRADIENT EFFECTS	0030
SURFACE ANALYSIS	0057
SURFACE PROPERTIES	0029
TEMPERATURE	0031
TESTING	0034
THE THEORY OF CRITICAL DISTANCES	0040
THEORY OF CRITICAL DISTANCES	0023
THIN STEEL WIRES	0039

KEYWORD	ABSTRACT
THIRD BODY	0055
THREADED CONNECTION	0010
TI-6AL-4V	008
TIO2	0026
TITANIUM ALLOY	0026
TORSION	0032
TORSIONAL FRETTING FATIGUE	006
TRANSITION	0017
VARIABLE AMPLITUDE LOADING	0038
WEAR	0022, 0023, 0027, 0053
WEAR ENERGY	0050
WEAR FATIGUE	0038
WEAR MECHANISM	0011
X20CR13	0054
XFEM	0048
ZIRCONIUM OXIDE	0013

ORGANISATION

UNIVERSIDAD DE SEVILLA

LABORATORIO INGENIERÍA MECÁNICA

SPONSORSHIP

Rtec instruments

Escuela Técnica Superior de
INGENIERÍA DE SEVILLA

CURTISS-WRIGHT

www.isff9.org