



3RD BRAZIL MRS MEETING

October 10-13, 2004

S Y M P O S I U M G:

IMPROVING FATIGUE AND MECHANICAL BEHAVIOR
IN STRUCTURAL COMPONENTS

Symposium Organizers:

Arnaldo H. Paes de Andrade (CCTM – IPEN – SP)

Herman Jacobus Cornelis Voorwald (DMT / UNESP – Guaratinguetá)

Valdir Alves Guimarães (DMT / UNESP – Guaratinguetá)

Sergio Frascino Muller de Almeida (CTA-ITA-IEM – S. J. dos Campos)

SYMPOSIUM G

IMPROVING FATIGUE AND MECHANICAL BEHAVIOR IN STRUCTURAL COMPONENTS

Monday, October 11

Session Chair: L. R. O. Hein (UNESP – Campus de Guaratinguetá)

10:30 Invited CRACK CLOSURE AND EFFECTIVE STRESS CHANGES DUE TO MEAN STRESS AND OVERLOADS IN AXIAL AND BIAXIAL FATIGUE
T. H. Topper (University of Waterloo - Ontario, Canada) (G – I001).

11:10 STUDY OF MICROSTRUCTURAL AND MECHANICAL BEHAVIOR OF TITANIUM ALLOYS
H. M. Silva, ITA; S. G. Schneider, FAENQUIL; S. Schneider, FAENQUIL;
C. M. Neto, ITA (G – O004).

11:25 CREEP BEHAVIOR OF AISI 310 STAINLESS STEEL AT 700 °C. PART 1:
ANALYSIS BASED ON CONSTANT STRESS TESTING DATA UNTIL RUPTURE
L. O. Bueno; A. Contin Jr., UFSCar (G – O005).

11:40 MECHANICAL TRIBOLOGY STUDY OF Ti NITRIDED BY GLOW DISCHARGE
G. B. Souza; C. E. Foerster, S. L. R. Da Silva, UEPG; C. M. Lepienski, UFPR
(G – O009).

11:55 EFFECT OF ISOTHERMAL AGING ON THE MECHANICAL BEHAVIOR OF A NICKEL BASE SUPERALLOY (59-23Cr-16Mo)
F. A. Darwish; E. S. Nicoletti, G. Solórzano, PUC-Rio (G – O011).

12:10 FATIGUE CRACK INITIATION MECHANISMS OF TWO AUSTENITIC STAINLESS STEELS BIOMATERIALS
E. J. Giordani; C. A. Mazzei; C. V. Leal; I. Ferreira, DEMa/FEM/UNICAMP
(G – O013).

12:25 LUNCH

Session Chair: H. J. C. Voorwald (UNESP – Campus de Guaratinguetá)

14:00 Invited IN SITU FRACTURE TOUGHNESS MEASUREMENT USING SEM.
J. P. Ipiña (Universidad Nacional del Comahue - Neuquén, Argentina) (G – I002).

- 14:40 MECHANICAL BEHAVIOR OF POLY (3-HYDROXYBUTIRATE) PROCESSED BY COLD COMPACTION AND INJECTION MOLDING. S. H. Pezzin, UDESC; M. A. T. Duarte, UDESC; R. G. Huguen, SEW Eurodrive; C. F. Julio, UDESC; A. P. T. Pezzin, UNIVILLE (G – O002).
- 14:55 TOUGHNESS OF HYBRID BAMBOO-WOLLASTONITE FIBER REINFORCED CEMENT COMPOSITES. F. A. Silva, COPPE/UFRJ; K. Ghavami, PUC-Rio; J. R. M. D'almeida, PUC-Rio (G – O001).
- 15:10 STRESSES AND FATIGUE BEHAVIOUR OF HOT DIP GALVANIZED COATINGS. C. Camurri ; R. Benavente ; C. Carrasco .; I. Roa .; Universidad de Concepcion, Departamento Ingenieria de Materiales – CHILE (G – O014).
- 15:25 MECHANICAL PROPERTIES OF TPS PLASTICIZED WITH ETHYLENE GLYCOL. A. L. Róz; A. A. S. Curvelo, USP (G – O015).
- 15:40 SUPERPLASTIC BEHAVIOR OF AN AUSTENITIC Fe-Mn-Al STEEL. P. Jr. Guanabara ; L. O. Bueno, UFSCar (G – O016)
- 15:55 COFFEE-BREAK
- 16:20 POSTER SESSION

Tuesday, October 12

- Session Chair: A. H. P. de Andrade (IPEN)
- 08:00 FATIGUE AND LONG TERM STABILITY OF SUPERELASTIC NiTi WIRES IN ANTI-SEISMIC APPLICATIONS. A. Yawny, CAB-CNEA Bariloche, Argentina; V. Torra, ETSECCPB-UPC, E-08034, Barcelona - Catalonia-Spain , M. Sade, CAB-CNEA; F.C. Lovey, CAB-CNEA (G – O001).
- 08:15 FATIGUE TESTING AND EXPERIMENTAL AND NUMERIC STUDIES OF ELECTRO-OPTICAL FLEXIBLE PIPES (UMBILICALS). P. F. Lépre; M. A. B. Martinez, USP (G – O003).
- 08:30 FATIGUE FAILURE OF TWO LARGE STEEL PINIONS. I. Ferreira, UNICAMP; H. A. Badin, PTI; E. J. Giordani, UNICAMP; A. C. A. Mazzei, UNICAMP (G – O006).
- 08:45 FATIGUE FAILURE OF A SPINE PROSTHESIS.

I. Ferreira; E. J. Giordani; A. C. A. Mazzei, UNICAMP (G – 0007).

09:15 MEAN STRAIN INFLUENCE IN LOW CYCLE FATIGUE BEHAVIOR OF AA7175-T1 ALUMINUM ALLOY.

G. Salerno, ITA; C. M. Neto, ITA; R. Magnabosco, FEI (G – 0008).

09:30 ON CRACK GROWTH RETARDATION IN A STRUCTURAL STEEL DUE TO A SINGLE OVERLOAD CYCLE.

F. A. Darwish; M. V. Pereira; M. Lopes, PUC-Rio; A. Camarão, GEP / ArvinMeritor CVS; S. Motta, Technology Division / Brasilamarras (G – 0012).

09:45 Invited DETERMINATION OF CRACK OPENING STRESS AND EFFECTIVE STRAIN-LIFE AND EFFECTIVE CRACK GROWTH CURVES FROM SMOOTH SPECIMEN FATIGUE DATA.

T. H. Topper (University of Waterloo - Ontario, Canada) (G – I003).

10:10 COFFEE-BREAK

Wednesday, October 13

16:20 POSTER SESSION

INVITED PRESENTATIONS

- G – I001 CRACK CLOSURE AND EFFECTIVE STRESS CHANGES DUE TO MEAN STRESS AND OVERLOADS IN AXIAL AND BIAXIAL FATIGUE
Timothy H. Topper Civil Engineering Dept, University of Waterloo, Waterloo, ON, Canada.

It will show investigations results of the effect of mean stresses normal to the crack plane on fatigue damage in uniaxial and torsional fatigue and of the effect of near yield stress overloads on fatigue damage in uniaxial and biaxial fatigue at various strain ratios. For uniaxial fatigue the results showed that the effective stress range at the fatigue limit was the same for all mean stresses. The fatigue limits stress range decreased linearly with increasing mean stress and crack opening stress until the point at which the crack opening stress fell below the minimum stress and the crack remained open. Then the fatigue limit stress range remained constant. A similar linear decrease of shear stress range, at a given fatigue life, with increasing mean stress normal to the crack was observed up to the mean stress at which the crack remained open. Again there was no further decrease in stress range beyond this point. Tests in which overloads were inserted between smaller constant amplitude small cycles frequently enough to result in cracks that remained open at various biaxial strain ratios resulted in strain-life curves identical to those obtained when high mean stresses were used to maintain open crack growth.

- G – I002 IN SITU FRACTURE TOUGHNESS MEASUREMENT USING SCANNING ELECTRON MICROSCOPY
Juan Perez Ipiña. Universidad Nacional del Camahue, CONICET, Neuquén, Argentina.

In situ tests were developed to measure fracture toughness (K_{Ic} , J_{Ic} , CTOD, R-curves) in small samples, simultaneously observing details of the crack blunting, initiation, and propagation by using scanning electron microscopy (SEM). A small load frame was employed for this purpose and in situ tests were performed in a Philips 515 SEM with a small chamber. A load-load line displacement record could be obtained from the different types of tests in order to calculate any fracture mechanics parameter, determine the initiation and amount of stable crack growth, measure directly the CTOD or Schwalbe's δ_5 and correlate any of these parameters with the observed micromechanisms. The applicability of the proposed in situ fracture toughness measurement technique has been exemplified making use of a wide set of materials, and its limitations were also evaluated.

DETERMINATION OF CRACK OPENING STRESS AND EFFECTIVE STRAIN - LIFE AND EFFECTIVE CRACK GROWTH CURVES FROM SMOOTH SPECIMEN FATIGUE DATA

Thimothy H. Topper. Civil Engineering, University of Waterloo - Ontario, Canada

Fatigue life predictions for notched specimens subjected to service load histories require information about the changes in crack closure due to overloads and the effect of these crack closure changes on the crack growth rate of small cracks growing from the notch roots. A methodology developed by our research group will be described to obtain high stress crack closure and crack growth information from inexpensive fatigue tests of smooth specimens. An effective strain-life curve is established by applying periodic overloads during otherwise constant amplitude loading of smooth specimens. The overloads are applied frequently enough that the crack opening stress remains below the minimum stress of the small cycles and they remain closure free and their stress ranges are fully effective. A conventional fully reversed constant amplitude strain-life curve is also obtained. The difference between the strain ranges at a given fatigue life for the two curves is equal to the closed part of the stress range for the constant amplitude curve. This data is used to calibrate an empirical crack opening stress model over the complete range of stress levels used in the fatigue tests. An effective (closure free) crack growth rate curve is obtained from the effective strain life curve as the inverse of the problem of predicting the effective strain life curve from crack growth rate data. Crack opening stress and crack growth rate data obtained by the present method are compared with results obtained by our group by direct physical measurements. The agreement is good.

ORAL PRESENTATIONS

G – 0001 FATIGUE AND LONG TERM STABILITY OF SUPERELASTIC NITI WIRES IN ANTI-SEISMIC APPLICATIONS

A. Yawny, M. Sade, F. C. Lovey. CAB-CNEA. Centro Atómico Bariloche, 8400, San Carlos de Bariloche, Argentina; V. Torra. ETSECCPB-UPC, E-08034, Barcelona - Catalonia-Spain.

Shape Memory Alloys (SMA) are an especial type of solids showing particular behaviour compared with traditional structural materials. From the different alloys systems of this class only two have reached technical relevance: NiTi and Cu-based alloys. Different applications have been realised until now, ranging from biomedical devices to mechanisms for the aerospace industry. Increasing interest exists on the use of SMA as damping material in anti-seismic applications. Responsible for this peculiar energy dissipation capability is the existence of a hysteresis associated with a stress induced martensitic transformation. Previous efforts mainly concentrated on basic material characterisation and formulation of constitutive models. Typical seismic loading profiles however, consist of long periods of static activity interspersed with short periods of intense seismic activity. An efficient use of a SMA requires therefore the consideration of fatigue effects and long-term stability of the behaviour. In the present work these two aspects are investigated. Results indicate that cycling leads to a decrease in the stress to transform and retransform, a decrease in hysteresis and build-up of non-recoverable strain. The long-term stability has been preliminary characterised by performing hold experiments at different amounts of transformed material and our results suggest, contrary to what has been supposed up to date, that NiTi alloys are prone to behaviour drifts.

G – 0002 MECHANICAL BEHAVIOR OF POLY (3-HYDROXYBUTIRATE) PROCESSED BY COLD COMPACTION AND INJECTION MOLDING

S. H. Pezzin, M. A. T. Duarte, C. F. Julio. UDESC - Centro de Ciências Tecnológicas-UDESC, Campus Universitário s/n, Joinville-SC, Brazil, Caixa Postal 631, CEP 89223-100. R. G. Hugen, S. E. W Eurodrive, A. P. T. Pezzin. UNIVILLE.

Aiming the development of high-performance biodegradable polymeric materials, the properties and the processing behavior of poly (3-hydroxybutyrate), PHB, have been investigated. Two samples of PHB obtained from sugarcane and characterized by infrared spectroscopy and X-ray diffraction, with molecular weights of $2,4 \times 10^5$ g mol⁻¹, PHB (A) and $3,0 \times 10^5$ g mol⁻¹, PHB (B), were used. Differential scanning calorimetry (DSC) showed that the samples were different regarding the crystallinity degree, 49% for the PHB (A) and 60% for the PHB (B), the glass transition temperature (T_g), 2,0°C (A) and 4,4°C (B), and the melting temperature, 178°C (A) and 171°C (B). The samples have been processed through high-pressure compacting, solid state extrusion, and injection molding. Cylindrical billets of PHB prepared by compaction at 200 MPa showed high Shore hardness, 71.3 (±0.9) D, and compression strength, 51.7 (± 1.0) MPa. The solid state processing was carried out by uniaxial compression, at temperatures between the T_g and the melting point, through conical dies with extrusion draw ratios of 25 and 4. It has produced extremely fragile materials with very high crystalline degrees (ca. 90%). Specimens of PHB (B) obtained by injection molding showed tensile strength, 24.53 (± 0.77) MPa, and modulus, 3.82 (±0.06) GPa, compatible to diverse types of applications.

- G – 0003 FATIGUE TESTING AND EXPERIMENTAL AND NUMERIC STUDIES OF ELECTRO-OPTICAL FLEXIBLE PIPES (UMBILICALS)
P.F. Leporé, M. A. B. Martinez. USP - Laboratório de Estruturas e Materiais Estruturais, Av. Prof. Almeida Prado, 83, trav.2, São Paulo, Brazil.

Floating systems are an attractive concept for production of oil and natural gas from deep water or marginal fields. That kind of system will, in general, require flexible pipes for production and control from wellheads to the surface. Umbilicals are a type of flexible lines, composite products made up of several steel and plastic concentric layers which working together, gives strength and leakproofness. Their primary functions are transmitting hydraulic, electric and optical signals from the surface. The structure of an umbilical shall be able to resist severe loads, which act in the usual operational conditions of an offshore production platform, in the particular case of Brazil, for ultra-deep waters (2.000 meters).

Besides, these structures, as permanent risers on floating production units, will be exposed to dynamic loads from waves and from movements of the vessel during their operational life or even during the process of installation. Hence, certain regions of a pipe may be limiting with regard to fatigue life. Therefore, this work deals with fatigue testing, stress analysis, and fatigue experimental and numeric modeling of 6 specimens of one type of 2 inches electro-optical flexible pipe (umbilical). The experimental tests were carried out in two test rigs assembled to simulate the umbilical lifetime (operation) and the installation process, both combining axial and bending loads. Good correlation was found between the observed and the theoretical behavior.

- G – 0004 STUDY OF MICROSTRUCTURAL AND MECHANICAL BEHAVIOR OF TITANIUM ALLOYS
H. M. Silva, C. Moura Neto. ITA. Pça Marechal do Ar Eduardo Gomes, 50, Vila das Acácias, São José dos Campos - SP, 12228-904, Brasil; S. G. Schneider, S. Schneider. FAENQUIL.

Recent studies have been done to achieve biomedical alloys containing non-toxic elements and presenting low elastic moduli. It has been reported that Ti-Nb-Zr alloys rich in beta phase have potential characteristics for substituting conventional materials such as Ti-6Al-4V, stainless steel and Co alloys. This work describes the microstructures and the mechanical properties of two b type titanium alloys, Ti-8Nb-13Zr and Ti-18Nb-13Zr (% wt). These alloys are produced from commercially pure materials (Ti, Nb and Zr) by arc melting under argon atmosphere in water – cooled copper hearth furnace. The obtained ingots, with initial diameter of 18 mm, are submitted to sequences of heat treatment (1000°C/60min and water quenching), cold-working by swaging procedures (89% plastic deformation) and in sequence other heat treatment (900°C/30min and air cooling). Microstructural analyzes of the materials in as cast and heat-treated conditions are performed using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS). Mechanical characterization of these alloys is based on tensile and hardness tests. Furthermore, the fracture surfaces are analyzed by using SEM. The elastic moduli of Ti-8Nb-13Zr and Ti-18Nb-13Zr alloys are 93 and 72 GPa, respectively. The results indicate that the route of thermomechanical processing is available to obtain an alfa+beta microstructure and good mechanical properties for the alloys, which can be used for biomedical applications.

- G – 0005 CREEP BEHAVIOR OF AISI 310 STAINLESS STEEL AT 700 °C. PART 1: ANALYSIS BASED ON CONSTANT STRESS TESTING DATA UNTIL RUPTURE.
L. O. Bueno, A. Contin Jr. UFSCar - Rod.W.Luiz, km.235 CEP-905 São Carlos (SP).

The creep behavior of AISI 310 steel was studied by constant stress tests from 70 to 375 MPa, at 700°C. The variation of the initial strain rates, secondary creep rates, rupture time, and final elongation with stress was observed. In secondary stage, power law was verified, with an exponent $n=4.3$ from about 70 to 120 MPa and $n=7.2$ from about 120 to 275 MPa. Mathew initial strain rate was also verified to follow a power-law relation with two n values similar to the secondary stage in the same stress ranges. Some tests were also carried out at 4 temperature levels from 600 to 670°C, to evaluate the apparent activation energies in the same stress ranges. Another series of n measurements were performed at 3 different strain levels corresponding to middle of primary, onset and middle of tertiary stage, by small stress variations on the applied stress level, to establish a comparison of the results with the classical secondary stage measurements. The creep data were also analyzed in terms of the dependence of rupture time with the secondary stage strain rate and applied stress considering classical parameterization methodology. Considerations are presented concerning the relation between the various n exponents and A coefficients which indicating the possibility of rationalization of creep behavior in terms of an effective stress given by a difference between the applied stress level and an internal stress level introduced during the creep process in this material.

- G – 0006 FATIGUE FAILURE OF TWO LARGE STEEL PINIONS
I. Ferreira, E. J. Giordani, A. C. A. Mazzei. Departamento de Engenharia de Materiais, Faculdade de Engenharia Mecânica, UNICAMP, Campinas, SP, Brasil, CEP 13083-970, Caixa Postal 6122; H. A. Badin. PTI.

The problem of fatigue of steel gears and pinions is a longstanding one. In spite of exhaustive researches, computer assisted designs, and modern steel vacuum manufacturing techniques; failure of machine elements from fatigue continues to occur, particularly in large components. This paper discusses the results of an failure analysis of two large forged pinions, of same dimensions, made of 17CrNiMo6 steel (DIN 17210), and used in two different gear boxes, both of 1,500 HP specific power. One of the pinions had a complete fatigue failure within three months and the other one had only a crack, started in the same position of the first pinion, twelve months after beginning of operation in two different gearboxes. In both pinions, the fracture initiated from the keyways. The obtained results in terms of chemical composition, microstructure analysis (tempered martensite and bainite in the core of the pinion with grain size ASTM 8), and hardness (from 35 to 39HRC) of the steel pinion are in accordance with the DIN and the gear maker standards. Tension and fracture toughness tests were conducted in order to evaluate the yield strength (873MPa) and tensile strength (1,100MPa), reduction of area (53%), and CTODc parameter ($d_c=0.033\text{mm}$). As a result of the analysis it was possible to conclude that the main cause of the pinion failure was overload.

G – 0007 FATIGUE FAILURE OF A SPINE PROSTHESIS

I. Ferreira, E. J. Giordani, A. C. A. Mazzei. Departamento de Engenharia de Materiais, Faculdade de Engenharia Mecânica, UNICAMP, Campinas, SP, Brasil, CEP 13083-970, Caixa Postal 6122.

Despite all technological research in biomaterials science, implanted prosthesis still failure. When a failure occurs in an implanted prosthesis, besides the necessity of a surgical removal, there is still all the pain and uneasiness suffered by the patient. In this work, a case of failure in a rod spine prosthesis - 6 mm in diameter and 120 mm in length - is discussed. The prosthesis was implanted in a 37-year-old female patient and the failure occurred 18 months after its implantation. The prosthesis was placed in the inferior region of the spine. The analysis revealed that the chemical composition, microstructure, and hardness, evaluated for the prosthesis' material - titanium alloy Ti-6Al-4V ELI -, were in accordance with ASTM F 136. Then, the fracture surface of the prosthesis was compared with fracture surfaces obtained from a standard fatigue test conducted in a sample of ASTM F 136 titanium alloy. Comparing the fracture surface of the prosthesis with the one obtained from the fatigue tests it was concluded that the cause of the prosthesis failure was fretting-fatigue-corrosion. Furthermore, it was also concluded that the fretting-fatigue-corrosion failure occurred because the prosthesis implanted in the patient does not have enough strength, in terms of this failure mechanism, for implantation in the lower region of the spine as a permanent implant

G – 0008 MEAN STRAIN INFLUENCE IN LOW CYCLE FATIGUE BEHAVIOR OF AA7175-T1 ALUMINUM ALLOY

G. Salerno, C. M. Neto. ITA - Departamento de Mecânica, Praça Marechal Eduardo Gomes, 50, São José dos Campos, São Paulo, Brazil, 12228-900; R. Magnabosco. FEI.

This work characterizes AA7175-T1 aluminum alloy under cyclic loading, obtaining the fatigue ductility and strength exponents and coefficients related to strain influence on fatigue life. It also checks the mean deformation influence on low cycle fatigue life, using fatigue equations developed by Morrow. Test specimens were produced from 20 mm diameter round bars, and the uniform gage section of the specimens was polished with chromium oxide. The monotonic behavior of the alloy is determined by seventeen tension tests conducted in a 250 kN MTS universal machine. An accurate study of monotonic tests allows the determination of the strain hardening coefficient and exponent of the Ramberg-Osgood relation. Strain-controlled tests, using a 25 mm gage length extensometer, were conducted in the same equipment, in strain amplitudes from 0.5 to 2 %, obtaining the total number of cycles to failure for a given strain amplitude at mean deformation varying from 0 to 1,5%. Strain-life curves obtained for different mean strain show different fatigue strength and ductility exponents and coefficients. These values are dependent of mean deformation values applied in the tests. The material studied is characterized under low cycle fatigue for zero mean strain, and using these data it is proved the validity of Morrow's relationships to define the AA7175-T1 alloy cyclic behavior, except for cycles to failure under 30.

G – 0009 A MECHANICAL AND TRIBOLOGICAL STUDY OF Ti NITRIDED BY GLOW DISCHARGE

G. B. de Souza. UEM - Departamento de Ciências, Av. Reitor Zeferino Vaz, s/n, Jardim Universitário, 87360-000, Goioerê, PR, Brazil; C. E. Foerster, S. L. R. Silva. UEPG. C. M. Lepiński. UFPR

Titanium and its alloys have many advantages for industrial and biomedical applications. These Ti based materials present low density, high melting point and good corrosion and fatigue resistance. However, for biological applications, as for bone prosthesis, it is necessary to improve their tribological properties maintaining the indispensable osseo adhesion character. In the present work, samples of commercially pure Ti were nitrided by glow discharge at a nitrogen-hydrogen atmosphere of 60%N₂/40%H₂ and temperatures ranging from 600°C to 900°C. Nitrides phases (TiN and Ti₂N) and surface oxidation (TiO and TiO₂) were identified by X-ray diffraction analysis. Nuclear reaction was also performed to obtain the elemental profiles (N, H and O). Elastic modulus (E) and hardness (H) profiles were determined by nanoindentation technique according to the Oliver-Pharr method. At near surface region (250 nm), the best mechanical improvement was obtained for the sample worked at 900°C. The elastic modulus was 309 GPa and the hardness 24 GPa. This means an increase in respect to the bulk values in the order of twice and 7 times, respectively. The friction coefficient was measured by pin-on-disk technique and the results also indicated that the sample nitrided at 900°C showed relevant improvement on its tribological performance. The friction coefficient was reduced in 21%, varying from 0.206 (untreated Ti) to 0.163 after nitriding at 900°C.

G – 0010 TOUGHNESS OF HYBRID BAMBOO-WOLLASTONITE FIBER REINFORCED CEMENT COMPOSITES

F. A. Silva, COPPE/UFRJ. Pedro Lago 62/201, Rio de Janeiro - RJ - 22621-110. K. Ghavami, J. R. M. Almeida. PUC-Rio.

This work presents an experimental and theoretical study on the toughness behavior of hybrid bamboo-wollastonite cement composites. For the toughness characterization of the material, two types of tests were chosen: three point bending test and Charpy impact test. Both tests had the same boundary conditions and same specimen's length and thickness. The plain matrix (C0), bamboo reinforced composite (BRC), wollastonite reinforced composite (WRC) and hybrid bamboo-wollastonite reinforced composite (BWRC) were tested using the two experimental procedures. The cementitious composites were produced following the Hatschek method. Mathematical equations, adapted from the literature, were used to predict the toughness and confront the experimental values obtained. It was found that for the three point bending test, BWRC had a superior performance when compared to that of the plain matrix, to that of the BRC and to that of the WRC. For the Charpy impact test it was found that the BWRC had a similar behavior to that of the BRC and WRC. Their behavior was, nevertheless, far better than that of the plain matrix. The mathematical formulation used to calculate the toughness, has given excellent results when compared to the three point bending tests. After the mechanical tests, the fracture surface of the failed test specimens was observed using a scanning electronic microscope (SEM) and the failure mode of each composite was established.

- G – 0011 EFFECT OF ISOTHERMAL AGING ON THE MECHANICAL BEHAVIOR OF A NICKEL BASE SUPERALLOY (59-23Cr-16Mo)
F. A. Darwish, E. S. Nicoletti, G. Solórzano. PUC-Rio. Rua Marquês de São Vicente 225, Gávea, 22453-900 Rio de Janeiro, Brazil.

The nickel base superalloy, 59-23Cr-16Mo, was developed in the nineties and has since been used in chemical and petrochemical industries as well as in equipment for environmental control. Exposure to high temperature is expected to result in microstructural changes, which, in turn, would affect the mechanical behavior of the alloy. With the purpose of elucidating the relation between the mechanical properties and pertinent microstructural aspects, specimens were taken from the as-received alloy and submitted to isothermal aging at two different temperatures of 700 and 900°C, for time intervals varying from 1 to 100 hours. A large population of nanoscale precipitates, referring to the Ni₂ (Mo, Cr) phase, was detected in all of the microstructural conditions considered in this work. In addition, the aged specimens were also found to contain microscale Ni (Mo, Cr)₂ particles formed at the grain boundaries via ordering reactions occurring preferentially in the grain boundary area. The mechanical behavior of the aged alloy is strongly related to the precipitation of this microscale phase, which governs the ductility level as well as the transition in the fracture mode from intragranular to intergranular. The plastic flow curves, obtained by uniaxial tensile testing, were modeled and the strain hardening exponent was found to suffer slight variation with the aging temperature and time, in virtue of the fact that the population of nanoscale precipitates is not affected by aging.

- G – 0012 ON CRACK GROWTH RETARDATION IN A STRUCTURAL STEEL DUE TO A SINGLE OVERLOAD CYCLE
F. A. Darwish, M. V. Pereira, M. Lopes. PUC-Rio. Rua Marquês de São Vicente 225, 22543-900 Rio de Janeiro, Brazil; A. Camarão. GEP / ArvinMeritor CVS. S. Motta. Technology Division / Brasilamarras.

It has been known for more than four decades that overload cycles of sufficient magnitude can result in transient retardation in the rate of fatigue crack growth at the baseline level. Following an overload cycle, the fatigue crack starts to advance into the overload (OL) plastic zone and the residual compressive stresses in an element just behind the crack tip are relaxed. This contributes to the level of crack closure in the wake of the crack tip, thus retarding fatigue crack propagation. As the crack exits the OL plastic zone, the propagation rate is generally back again at the baseline level corresponding to the constant amplitude (CA) loading. Accordingly, the delay period is expected to be related to the monotonic plastic zone size. However, a number of models recognize that new plastic zones are created inside the large OL plastic zone and crack growth retardation will also depend on the cyclic plastic zone size. Experimentally, the delay period corresponds to fatigue crack extension in the interval between the moment the overload is applied and the moment propagation rate is back to the baseline level. With this in mind, the present study was initiated to evaluate the applicability of such models to predicting fatigue crack growth retardation brought about by a single overload cycle applied at a given crack length during CA loading of an R3 grade structural steel. The steel was fatigue tested in different microstructural conditions obtained by quenching and tempering.

G – 0013 **FATIGUE CRACK INITIATION MECHANISMS OF TWO AUSTENITIC STAINLESS STEELS BIOMATERIALS**

E. J. Giordani, A. C. A. Mazzei, C.V. Leal, I. Ferreira. DEMa/FEM/UNICAMP - Depto de Engenharia de Materiais, Faculdade de Engenharia Mecânica, UNICAMP, Campinas, SP, Brasil, CEP 13083-970, Caixa Postal 6122.

The main purpose of this study was to investigate the fatigue and corrosion-fatigue crack initiation mechanism of two austenitic stainless steels biomaterials, named ISO 5832-9 and ASTM F 138, since these mechanisms are not well known. This investigation was conducted by SEM on specimens subjected to neutral (air) and aggressive (0.9%NaCl solution) axial fatigue tests. Fractographic analysis revealed that fatigue and corrosion-fatigue crack initiation occurs preferentially in the elongated and coarse Z-phase (CrNbN) precipitates in ISO 5832-9 steel. Crack initiation is caused by particle rupture rather than by particle-matrix decohesion. The results of this analysis suggest that coarse Z-phase precipitates are detrimental to the fatigue properties of the material. These precipitates reduce the time elapsed for the onset of corrosion-fatigue crack initiation and early crack propagation. The preferential sites for the initiation of main fatigue and corrosion-fatigue cracks in the ASTM F 138 steel are grain boundaries, usually associated with much larger grains (> 120 μm) than that the average grain size (approximately 60 μm) determined for the condition studied. This finding confirms the importance of the grain size in the fatigue properties and suggests that refining the grain of the F 138 steel would be an important alternative to increase the fatigue and corrosion-fatigue resistance of the material.

G – 0014 **STRESSES AND FATIGUE BEHAVIOUR OF HOT DIP GALVANIZED COATINGS**

Carlos Camurri P. Raul Benavente G. Claudia Carrasco C. Isidoro Roa S. Universidad de Concepcion, Departamento Ingenieria de Materiales. Casilla 160, Correo 3, Concepcion, CHILE.

The goal of this work is the study, by means of three points flexion tests in an Instron machine, of the effect of stresses in the range 228 to 578 MPa and cycles up to 700 and frequency of 0.25 Hertz, on hot dip galvanized coatings on a SAE 1020 substrates. SEM and optical microscopy was use for the characterization of the coatings before and after flexion, recording the primary and total cracks respectively, been the reference gage length 1 mm. The zinc baths at 450°C contains also 0.16% Ti, 0.02% Fe, and variables Al and Ni weights percents between 0-0.28% and 0-0.3% respectively. The main results are: -The effect of the applied tensile stresses is the one to increase the number of cracks and to foment the propagation of the same in direction perpendicular to the substrate. The number of cycles as not effect on crack number For stresses lower than 386 MPa the number of cycles as not effect on cracks propagation. This result is concordant with Kitagawa works. On the contrary for stresses over than 386 MPa the number of cycles contributes to cracks propagation and have a deleterious effect on the quality of the hot dip galvanized coatings. To prevent fatigue crack propagation the best bath composition are those than form thinner fragile layers in the galvanized coating. In this case, Zn-Fe-Ti-0.012% Al or Zn-Fe-Ti-0.01% Al-0.038% Ni.

- G – 0015 MECHANICAL PROPERTIES OF TPS PLASTICIZED WITH ETHYLENE GLYCOL
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The interest in using starch as biodegradable materials has been actively pursued in recent years. The reason for this interest is the high availability of starch, its renewable character and its low cost, which make it one of the most competitive raw materials for the production of biodegradable plastics. Starch has gained attention as an alternative viable biodegradable plastic with the introduction of thermoplastic starch (TPS) materials, which are obtained by processing native granular starch in the presence of hydroxyl-bearing additives capable of forming strong hydrogen bonds with it. The quantity of plasticizer and its chemical nature exert a great influence on the physical properties of the processed starch. The plasticizing effect of ethylene glycol on regular cornstarch was investigated by melt processing of regular cornstarch in an intensive batch mixer at 150°C. Ethylene glycol concentration was varied from 15 to 40 wt %. Mechanical analysis were performed to investigate the effect of plasticizer concentration in TPS samples. The Storage Modulus (E') increase with increasing of plasticizer content, up to 30% of ethylene glycol. After this percentage, the modulus decreased. The decrease in the storage modulus can readily be ascribed to the plasticizing role of ethylene glycol. The crystallinity increases as the plasticizer content increases, thus inducing a stiffening of the material, resulting in increase of organization of matrix and small mobility.

- G – 0016 SUPERPLASTIC BEHAVIOR OF AN AUSTENITIC Fe-Mn-Al STEEL
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Information on superplastic behavior of Fe-Mn-Al alloys are extremely scarce in the literature. There is some indication, however, that these materials may exhibit such behaviour with possibility of application in practice [Toscano (1983)] in the same way as Fe-Cr-Ni duplex stainless steels. This work presents a study on the hot tensile properties of an Fe-26Mn-7Al-1C steel, with the determination of the variation of the strain-hardening and strain-rate sensitivity parameters in various temperature levels from 600°C to 900°C and strain rates from 1×10^{-5} to $1 \times 10^{-2} \text{ s}^{-1}$, following different thermo-mechanical processing conditions applied to the material. The material was shaped by a controlled sequence of cold rolling and aging treatments into sheets about 1.5 mm thick, to assure an adequate fine grain structure. The results give clear indication of the material superplastic susceptibility and suggest possibilities of its application in components produced by superplastic forming.

POSTER PRESENTATIONS

- G – P001 SELF-CURING ACRYLIC CEMENTS FORMULATED WITH Bis-GMA
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Experimental cement formulations were prepared by replacing part of the methylmethacrylate (MMA) liquid phase of a conventional surgical cement by an equivalent weight of 2,2-bis [4(2-hydroxy-3-methacryloxypropoxy) phenyl] propane (Bis-GMA), which is the reaction product of Bisphenol A and methacrylic acid. It was found that up to 50 weight percent of the MMA could be replaced by Bis-GMA without reductions in flow characteristics of the precured polymers. Cements containing 20, 30, 40 and 50 weight percent of Bis-GMA in the liquid component were prepared. Over this range of Bis-GMA weight percent, it was found that, relative to the unmodified cement, the volumetric shrinkage (DV), the peak temperature reached during the polymerization reaction (Tp), and the flexural strength (obtained in three-point bending tests) were each significantly reduced, while there were no significant effects on any of the other properties determined, namely, degree of conversion of the monomer during the polymerization reaction, the glass transition temperature, the compressive strength, and the flexural modulus. The increase in the crosslinking density with increasing amount of Bis-GMA renders the polymer matrix more brittle. This feature was considered responsible for the reduced flexural strength. However, the drops in DV and Tp indicate that cements whose liquid monomers are modified using Bis-GMA hold promise for use in anchoring total joint replacements.

- G – P002 MORPHOLOGICAL, MECHANICAL AND FRACTURE PROPERTIES OF MATERIALS BASED IN MODIFIED DIVINYLESTER RESINS (DVER)
W. F. Schroeder, M. I. Aranguren, J. Borrajo. INTEMA. Juan B. Justo 4302, B7608FDQ Mar del Plata, Argentina.

The improvement of properties of a thermoset by the addition of a thermoplastic is one of the reasons of the great importance of thermoset-thermoplastic blends. The final properties of the obtained materials are related to their morphologies generated during the polymerization, usually by a reaction-induced phase separation mechanism. The objective of this work is to evaluate the mechanical and fracture properties of poly (methylmetacrylate) (PMMA) modified DVER/styrene (S) thermosets and to relate them with the morphologies developed in the obtained materials. Two DVER were used in this study; a low molecular weight resin synthesized in our laboratory ($M_n=600$ g/mol), and a commercial resin of higher molecular weight (2100 g/mol). S-DVER mixtures with different proportions of S: 20, 45, 70 % by wt. were prepared; and modified with different contents of PMMA from 0 to 20 % by wt. The mechanical properties of the obtained materials were determined using an Instron Universal Testing Machine in compression and three-point bending tests. The fracture mechanics measurements were made at room temperature, using three-point bending geometry on the same Testing Machine. The addition of a thermoplastic modifier allowed to improve the fracture resistance without the unwanted reduction in modulus, which is inevitable when using elastomeric additives.

- G – P003 **FAILURE ANALYSIS OF HARD METAL PUNCH USED IN STEEL PLATE STAMPING**
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Stamping tools are made of hard metal, which are widely used as tool materials for conformation and cutting. Tungsten carbide - base cobalt bonded is the main material used as tool, due to its desired properties combinations, such as, hardness, wear resistance and strength resistance. The main conditions supported by tools in stamping process are: wear under a complex and unusual loading conditions, complex thermo-mechanical loads, high temperatures, static and cyclic loads and corrosion. The stamping process has some advantages when compared with other processes of manufacture involving high taxes of production, e.g. the reduction of material loss, among others. However, the conforming process may induce high stresses in the work-piece and in the tool. In this work we propose a study to determine the main causes of failure of the stamping tool, since the failures have not only one origin. The characteristics of the failure are compared with the conventional failure mechanisms, including macro and micro characteristic of these failure mechanisms. The Tool was submitted to chemical analysis, X ray diffractometer (DRX), analysis of the metallographic structure, hardness and fractography. This paper presents the detailed results of the analysis in order to determine the causes of failure, supplying the necessary subsidies to take corrective measures to prevent its recurrence in the future.

- G – P004 **INFLUENCE OF MICROSTRUCTURE IN THE IMPACT BEHAVIOR OF PRE-CRACKED SPECIMENS IN THE FRAGILE DUCTILE TRANSITION OF HIGH STRENGTH LOW ALLOY STEELS**
V. A. Guimarães, L. R. O. Hein, A. L. A. Kuriki. UNESP - FEG Av. Ariberto P. Cunha, 333.

The improvement of projects necessity has been stimulating researches of new materials classes. In the last decades intensive studies has been accomplished, in the sense of obtaining scientific and technological subsidies, about the performance of new materials. Materials as steel, that still represents the mechanical construction base, for their excellent behavior, low cost and relative abundance, has been throwing a great challenge: to ally mechanical resistance with toughness. The great technological progress in the development of materials of high resistance is reaching simultaneous increases of mechanical resistance and toughness. The present work consists of studying two structural steels to make possible a better understanding of the toughness variation in the ductile-fragile area, tends in view the great current difficulty in establishing an appropriate transition temperature, due to the high dispersal results by the Charpy method testing. The study intends to analyze the method seeking the decrease of the results dispersal and to simplify the transition temperature determination in relation to the complex and high cost experimental analytical method developed by the consortium ASTM - Oak Ridge National Laboratory, the norm ASTM E1921, proposal to decrease this difficulty. The results obtained with Charpy testing with pre-cracked specimens revealed a better definition of the transition temperature and also better mechanical properties for the API 5L X70 steel.

- G – P005 THE INFLUENCE ON MECHANICAL RESISTANCE OF PARTIAL REPLACEMENT OF NATURAL SAND BY CONCRETE RESIDUALS IN HIGH PERFORMANCE CONCRETE
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In concrete industry, the ever-increasing demand for natural sand has already extinguished several natural sources closer to the largest consumer centers, consequently raising raw and transportation material costs, therefore enhancing the search for alternative materials adequate for concrete manufacture. In addition, concrete technology development has since long been associated to high performance concrete (HPC). According to these ideas, the present work purports to study the mechanical behavior of HPC in which natural sand has been replaced by some definite amount of concrete residuals. Initially, in order to evaluate the influence on mechanical behavior of 50% concrete residuals in substitution to natural sand, the resistance under simple compression is determined. Results from HPC with and without residual inclusion are compared and the results thereafter show that resistance under simple compression obtained for HPC with residual addition is at least equivalent to the one obtained for normal HPC.

- G – P006 INFLUENCE OF TIME AND TEMPERATURE OF HEAT TREATING ON HARDNESS
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The Jorge Lacerda complex, a coal fired power plant, has 12 vertical roller mills, with 3 rollers per mill, totalizing 73 ton of roll material which is wear by the abrasive action during the coal grinding operation. The rollers were originally made of Ni-hard type 4 cast iron (ASTM A532 Class I D). Years ago they were replaced by the more wear resistant high chromium cast iron, ASTM A532, class II D (3% C, 20 %Cr e 2 % Mo), resulting in a life increase from 8.000 h to 12.000 h. Today the rollers average mass loss due to wear is about 13 ton /year. These rollers are produced by casting, followed by annealing (to decrease the hardness for easier machining), machining and air quenching (in order to increase the materials hardness). Although the present production practice employed on the Class II D high chromium cast iron resulted in the above mentioned increase in wear life, there are some doubts about the optimum time and temperature used in the final heat treatment (normalizing) cycle. In this respect, a research is being conducted to optimize the heat treatment cycle in order to increase de wear life of the rollers. This paper presents the hardness and wear behavior (measured by the dry sand rubber wheel test - ASTM G65) resulting from different time and temperature of the normalizing treatment. A discussion relating microstructure, hardness and wear behavior is also presented. The laboratory results points to a possible increase in the wear life.

- G – 0007 MOSSBAUER SPECTROSCOPY AND MAGNETIZATION STUDIES OF FE-RU DISORDERED ALLOYS
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In this work the disordered Fe-Ru alloys are investigated with several experimental techniques to study the composition dependence of its magnetic properties in the bcc and hcp phases. X-ray diffraction measurements indicate that the prepared samples are single phase with either bcc or hcp structures. At room temperature, Mossbauer spectroscopy measurements and thermal analysis show a ferromagnetic behavior for the samples in the bcc phase, whereas for the alloys with the hcp structure a paramagnetic behavior is observed. Solid solutions of Fe-Ru in the hcp phase are stable over an extended range of concentration. For $4.8 < x < 23.5$ coexist both the bcc and hcp phases, and for $x < 4.8$ the alloys are in the bcc phase. In alloy systems where the two component metals have similar outer electronic structures one expects that they should conform quite closely to Vegard's law, which gives a straight line joining the atomic volumes of the two elements. These systems can provide the ideal context for studying the effects of atomic size on the physical and mechanical properties of solid solutions.

- G – P008 **CONCRETE CREEP AT CONTROLLED AMBIENT CONDITIONS**
M. R. Morelli, W. Libardi, M. A. Coimbra. UFSCar. Departamento de Engenharia de Materiais, Rodovia Washington Luiz, km 235.

The purpose of this work was to present an experimental study on creep of concrete at controlled ambient conditions. The following parameters were examined: period (time) when the concrete was cast and loaded, cement type and concrete composition. The research significance was to study the effect of controlled ambient temperature and relative humidity on creep of concrete in specific machine of creep concrete tests. The results of the study will provide information on the effect of many factors on the time-dependent deformations of concrete and also help in modifying the present concrete creep models.

- G – P009 **NUMERICAL SIMULATION OF THE MECHANICAL DEFORMATION OF A COMMERCIAL BRONZE VALVE DUE TO THE PRESSURE GENERATED BY THE FLOW OF THE WATER**
E. Santos, A. C. Mossi, M. M. Pariona. UEPG - Campus Uvaranas, Bloco CIPP, Laboratório LIMAC.

The constituted material of the valve was commercial bronze and inside of the valve a rubber exists that controls the flow. The flow was studied varying the input velocity of the water and the aperture of the rubber was considered small and big. For the simulation process, first the rubber was considered more closed and soon more open, in each one of the cases, the input of the velocity was varied (of 1 up to 150 cm/s) with the purpose of generating low and high Reynolds' numbers, which it would provoke the turbulence. As result was showed the velocity and pressure field inside of the duct in qualitative and quantitative form, it presented the turbulence in all of the cases for the rubber most closed, the velocity of the exit was larger than of input, for the rubber most open it showed turbulence very a little, as consequently of this, the velocity of the exit of the flow was very larger in relation to the input velocity, also the maximum velocity was observed inside of the valve, being it larger in the valve most closed and the pressure field is inversely proportional to the variation of the velocity. In addition, the tension in the metallic structure was observed larger for the valve most closed and the tension distribution in the rubber it was smaller than in the metallic structure for both cases, the mechanical strain was more notorious in the rubber for the valve most closed, it was also observed for velocity larger than of 50 cm/s the rubber was deformed visibly.

- G – P010 **NUMERICAL SIMULATION OF THE FRACTURE MECHANICS OF THE ALUMINUM ALLOY 7075 IN TEMPERATURES OF THE ENVIRONMENT AND INTERMEDIATE**
A. C. Mossi. UEP, Campus Uvaranas Bloco CIPP, Laboratório LIMAC. M. M. Pariona. UEPG.

In this work, the numeric simulation of the fracture mechanics was accomplished in a piece of aluminum alloy 7075 through the technique of finite elements, considering a geometry propitiates for the existence of tensions concentration in the piece, when it is submitted to a constant external load. The fracture mechanics was studied as function of the variations, such as, of the size of the crack, of the applied tension and of the temperature. Where the applied tension was considered constant in three levels (50, 100, 150 MPa) in the temperature of the environment, soon it was studied when a tension of 50 MPa was applied in the temperatures of 50, 100 and 200 oC. The simulation was accomplished through the software of finite elements ANSYS, the result was shown graphically with tension distribution at the tri-dimensional geometry. The result for temperature of the environment was described in function of the tension intensity factor (K) and of the integral-J, for this, the size of the crack (reason of the length of the crack and the width of the sample) was varied maintaining constant the applied tension and the temperature. For this case, for the tension of 50 MPa the lineal behavior was observed until the reason of 0.5, but the tenacity of this material is reached for the reason of 0.15. For the tension 100 and 150 MPa the lineal behavior was until the reason of 0.35 and 0.25 respectively, but the tenacity for any reason was committed for these cases. For superior temperature

- G – P011 SHOT PEENING ON THE FATIGUE STRENGTH OF TI-6AL-4V ALLOY COATED BY HVOF.
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The increasingly design requirements for modern engineering application have stimulated the development of new materials with improved mechanical properties. For aerospace applications, investigations are aimed at strengthening mechanisms, plasticity, fatigue, environmental effects and dynamic and static fracture. Titanium is a material of recent industrial application, when compared with light steel and aluminum alloys. It is low density material combined with excellent weight/strength ratio as well as corrosion resistance, which make the titanium attractive for application in landing gears. The low wear resistance characteristic limits the full use of this material in the aeronautical industry. Fatigue, corrosion and wear resistance are fundamental parameters to be considered in the development of mechanical components. Fatigue specimens were coated with WC-10%Co-4%Cr by High Velocity Oxy-fuel (HVOF) process according with NEDE 40045 EMBRAER standard. Axial fatigue tests ($R = 0,1; f = 50\text{HZ}$) were realized. Experiments will consider as fatigue strength the complete fracture of the specimen or 107 load cycles. Three groups of specimens were prepared and tested to obtain SxN curves: base material (Ti-6Al-4V), base material coated by HVOF and base material shot peened and coated. Fracture surface analysis by SEM was performed. A reduction in the fatigue strength life of Ti-6Al-4V coated and a recovered of the shot peened material were observed.

- G – P012 FRACTAL AND ROUGHNESS ANALYSIS OF TI-6AL-4V FRACTURE SURFACE THROUGH EXTENDED DEPTH FROM FOCUS RECONSTRUCTION
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The fracture surface topography of Ti-6Al-4V solution treated titanium alloy have been analyzed about its roughness and fractal behavior and compared to plane strain fracture toughness data. Fracture toughness specimens have been machined for a range in width, from 12.7 mm to 19.3 mm, to obtain a range in toughness data. Sampling for surface analysis has been placed in three positions along the width for each specimen. Quantitative fracture investigation has been done through extended depth from focus reconstruction, based on light microscopy. Roughness data presented no significant relation with plane strain fracture toughness. The large scattering of fractal measurements along specimen width should limit the validity of models relating fractal values and fracture toughness. In all cases, a bifractal behavior has been observed. Despite of the large deviation on mixed fractal dimension values, it has also been observed a common point for the transition between '\macro\' and '\micro\' fractal dimension values (i.e., fractal data related to large and small resolution in probe scale), suggesting a dependency of fracture topography to some microstructural parameter.

- G – P013 MATHEMATIC APROXIMATION OF THE CREEP BEHAVIOR OF CONCRETE
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The purpose of this work was to present a mathematic approximation of the experimental study on creep of concrete. Viscoelastic behavior of early-age normal has been investigated. The study shows that concrete exhibits high compression creep strain if loaded at an age less than or equal to 1 day. Creep experiments were also carried out on concretes with same w/c (water/cement) ratios and some qualitative comments are made. Finally, an approach for mathematical modeling of early-age creep for normal concrete was explored.

- G – P014 **FRACTOGRAPHIC APPROACHES IN FATIGUE SPECIMENS AS A FUNCTION OF LOADING STRESS AND MICROSTRUCTURE**
M. A. Colosio. GM - General Motors do Brasil, Av. Goias 2880 - São Caetano do Sul, Brasil, CEP 09501-970; A. H. P. Andrade. IPEN.

The objective of this work is to compare typical differences in fractographic analysis obtained in notched and unnotched specimens tested in stress-controlled fatigue. Failure analysis procedure done in failed components normally describes the chronology of the events and the condition those have occurred. Following this line the current work characterized a typical change of fractographic aspects in similar specimens, which had been confectioned with the same material and submitted to the same thermal treatment, however with and without the presence of a superficial micro-notch. The experimental tests were done in a servo-hydraulic fatigue machine and later the fractured specimen surfaces were analyzed in a scanning electron microscope.

- G – P015 **DETERMINATION OF R-CURVES OF UNIDIRECTIONAL GLARE LAMINATES BY UNLOADING COMPLIANCE**
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The main objective of the work was to study the applicability of the unloading compliance technique for the determination of crack resistance curves of unidirectional Glare (fiber-metal laminate). The experimental evaluation of R-curves of SE (B) specimens ($W = 25.0$ mm) of Glare 1 3/2 notched longitudinal and perpendicular to the fibers direction was done. Besides the unloading compliance technique the crack growth evaluation was also performed optically. The fracture toughness values were measured through a recently proposed methodology for fracture toughness evaluation of fibre-metal laminates, based on small normalized specimens and elastic-plastic methodologies (J-Integral and CTOD of Schwalbe, δ5). Although more systematic experimental study is needed, the unloading compliance technique seemed to be applicable to unidirectional fibre-metal laminates, predicting with high degree of success the stable crack growth during the tests.

- G – P016 **MICROSTRUCTURAL AND MECHANICAL CHARACTERIZATION OF BIOMEDICAL Ti- Nb-Zr (-Ta) ALLOYS**
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Pure titanium and its alloys are the most attractive materials for biomedical applications due to their superior biocompatibility, appropriated physical and chemical properties. However, recent researches are directed to beta Ti alloys because they can exhibit an elastic modulus lower than others alloys, such as Ti-6Al-4V (alpha+beta). The aim of this work is to characterize the microstructure and mechanical properties of Ti-35, 3Nb-5, 1Ta-7, 1Zr and Ti-41,1Nb-7,1Zr alloys, in which the atomic amount of Ta will be substituted by Nb. These alloys are produced from commercially pure materials (Ti, Nb, Zr and Ta) by arc fusion under argon atmosphere. The obtained ingots ($\gg 160$ g and diameter $\gg 18$ mm) are submitted to sequences of heat treatment (1000°C/2h and water quenching), cold-working by swaging procedures (diameter $\gg 6,3$ mm) and other heat treatment (1000°C/2h and water quenching). Microstructural analyzes of the alloys in as-cast and heat-treated conditions are performed using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS). Mechanical characterization of these alloys is based on tensile and hardness tests. Moreover, the fracture surfaces are analyzed by using SEM. The obtained alloys show a microstructure containing alpha, beta and omega phases. Furthermore, the mechanical properties are suitable for biomedical applications, specially the elastic moduli that are lower than that of conventional Ti alloys and much close to that of the bone.

- G – P017 THE MECHANICAL PROPERTIES OF Cu-BASED SHAPE MEMORY ALLOYS REGARDING TO STRUCTURAL APPLICATIONS
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- The interesting particular properties of shape memory alloys (SMA) are the pseudoelasticity and the thermoelasticity, the damping and the shape memory effect. The shape change is related to a thermoelastic martensitic transformation between metastable phases. The ability to support large, recoverable strains at moderate stress levels, and the presence of a considerable hysteresis are important parameters. This makes these alloys attractive for long time guaranteed damping devices, for instance in civil and mechanical engineering. In Cu-based alloys (CuZnAl, CuAlBe, CuAlNi) both single-crystalline and poly-crystalline material are of interest. While the single-crystals are rather stable under pseudoelastic mechanical cycling, the mechanical properties of polycrystalline samples depends on the grain size, and evolves strongly on cycling. In this work, the behavior under cycling of specimens with different grain size are studied. The evolution of the various parameters, like the transformation stresses, the slope of the stress-strain cycles, the hysteresis width, the increase of remnant deformation and the shape recovery are investigated. From the results the performance of the material is analyzed and its potentialities and limitations are evaluated for different possible working conditions
- G – P018 CREEP BEHAVIOR OF AISI 310 STAINLESS STEEL AT 700 °C. PART 2: ANALYSIS BASED ON SMALL TEMPERATURE VARIATIONS AND STRESS DROP EXPERIMENTS.
L. O. Bueno, A. Contin Jr. UFSCar. Rod.W.Luiz, km.235 CEP13565-905 São Carlos (SP).
The creep behavior of AISI 310 steel was studied by constant stress tests from 70 to 375 MPa, at 700°C. The temperature dependence of secondary creep rate was determined by small changes of about 10°C above and below 700°C. Apparent activation energy values were found to be nearly constant and close do the self diffusion activation energy for the base metal. Stress variations of various magnitudes were made during the secondary stage to identify the transition region from forward creep to full anelastic creep behavior. Stress-drop experiments were also carried out and incubation periods systematically detected following the stress reductions. Recovery kinetics parameters and internal stress (or friction stress) data were determined by extrapolation using a numerical method of analysis based on the occurrence of creep controlled by the dislocation network growth. The friction stress was found to increase linearly with the applied stress from 70 to 120 MPa and reach a constant value equal to 66 MPa from 120 to 210 MPa. The secondary creep rate could be expressed by a power law relation in terms of the effective stress normalized by the yield stress of the steel at 700°C using a single stress exponent $n \sim 3.3$, for the whole stress range investigated. A general discussion is presented involving these and other results mentioned in Part 1 of this work towards a better understanding of creep behavior of the material under the present experimental conditions.
- G – P019 INFLUENCE OF FIBER ORIENTATION ON THE MECHANICAL PROPERTIES OF POLYESTER/JUTE COMPOSITES
L. H. Carvalho, S. M. L. Silva. UFCG. DEMa/CCT/UFCG, Caixa Postal 10034, Campina Grande, PB. CEP 58109-970.
Studies on natural fiber polymer composites are growing due to cost, environmental and mechanical properties considerations. Composite properties are dependent on composition, bond strength and fiber orientation. In this work the mechanical properties of compression moulded unsaturated polyester/jute composites were investigated as a function of fibre content and orientation. Jute fibers were washed, cut-up and dried in an oven for 30 minutes at 80°C and disposed in the mold. MEK-P (1%) catalysed unsaturated polyester was poured over the fibers, the mold closed (8 ton) and the force maintained for 4h at room temperature. Long unidirectional fiber composites with 0-50% w/w fiber contents were manufactured. A randomly distributed short fiber composite with 30% w/w was also manufactured. The tensile and impact properties of these composites were determined as a function of fiber content and orientation. Tensile testing was conducted according to ASTM D-3039 standards on a Lloyd LR-10K apparatus operating at 1mm/min. Izod impact testing took place on a Resil 5,5J apparatus operating with a 4J pendulum according to ASTM D-256 standards. Our results show properties to increase with fiber content. Significant increase in properties was obtained for the samples tested along the fiber axis, even at low fiber contents. Intermediate properties were obtained for the randomly aligned samples and lower properties were displayed by the composites tested transversally to the fiber axis.

G – P020 **MODELLING OF WATER SORPTION OF JUTE AND JUTE/GLASS FIBER FABRIC REINFORCED UNSATURATED POLYESTER COMPOSITES**
L. H. de Carvalho, W. S. Cavalcanti, A. G. B. Lima. UFCG - DEMa/CCT/UFCG, Caixa Postal 10034, Campina Grande, PB. CEP 58109-970.

Filler hybridization, either by the combination of laminates or by fiber mixing is a way of getting products with the desired properties. Hybrid composites with vegetal fibers and glass fibers are sufficiently resistant and lighter than those reinforced by glass fibers alone. This type of composite, however, tends to show delamination problems. This problem can be reduced by the use of hybrid fabrics in which different fibers are weaved or knitted together. In the present work compression molded unsaturated polyester composites reinforced with a Hessian cloth and a hybrid jute-glass fabric were manufactured. The composites had the following weight compositions: a) 26% jute/74% polyester and b) 26% jute/32% glass roving/42% polyester. The water sorption of these composites was determined on 20x20mm samples whose thicknesses varied in function of total fiber content and whose sides were resin coated to avoid capillarization. A 3-D mathematical transient model is presented to predict mass transfer during water absorption in unsaturated polyester composites reinforced by weaved fabrics made with single and hybrid fibers. The mathematical formulation was numerically solved using a finite-volume method and the implicit interpolation scheme. Predicted results on the average moisture inside the material during the whole process are shown and compared with the experimental data. A reasonable fit was obtained and a diffusion coefficient was obtained using a least quadratic error.

ACCUMULATED DAMAGE EFFECT ON CRACK PROPAGATION IN Al 2024 T3 ALUMINUM ALLOY

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G – P021 The aim of this study has been to investigate the effect of past loading on crack propagation in Al2024-T3 used in aircraft structures. This problem affects safety and maintainability relevant to ageing aircraft. This study attempts to determine if aluminum alloy that has experienced service loads over long periods of time will continue to be able to maintain the same crack resistant characteristics the material originally exhibited. This experimental study included 3 test sets. In first, the reference set, fatigue life under uniform cyclic loading was determined. Twelve samples of new material were tested under same loading regime with a maximum stress of about 75% of the materials yield strength and with a load ratio 0.1. In second set, 12 crack growth samples of Central Cracked type were tested under same loading regime in order to determine average crack propagation behavior and typical data distribution. In the third set, the central edge for crack nucleation was introduced after previous cyclic loading without stress concentration, after 3 exemplars had reached 2% of their estimated fatigue life and three other exemplars had reached 40%. The theoretical model for the study was based on Paris-Erdogan's kinetic equation. Measuring the results with a common exponent, the reference set showed a material coefficient of 6.36%, while the sets that had been exposed to cyclic loading equivalent to 2% and 40% of their estimated fatigue life showed material coefficients of 11.11% and 18.39% respectively. Further detailed investigation of this phenomenon is proposed.

G – P022 CRACK TIP PLASTIC ZONE NUMERICAL SIMULATIONS UNDER DIFFERENT LOADING MODES

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Many materials used in industrial applications have their fracture toughness increased with temperature. In the case of brittle and semi-brittle materials, this is associated with an increasing plastic zone that interacts elastically with the crack tip. Therefore, the phenomenon can be modelled in terms of mobility of individual dislocations that forms the plastic zone. In this work, dynamic numerical simulations of the plastic zone of a crack loaded under different loading modes were performed. The plastic zone size, the stress along the plastic zone, the number of dislocations and amount of shielding at the crack tip were calculated based on numerical simulations as a function of temperature, loading rate and dislocation mobility. Dynamic analytical models of the plastic zone were also developed from static models considering the plastic zone as a continuous distribution of infinitesimal dislocations and under a homogeneous internal stress. When this condition was met, the results from the numerical simulations agreed well with those calculated from the dynamic models. The results highlighted the role of dislocation mobility on crack tip shielding and the prediction of the brittle-ductile transition temperature.

G – P023 CREEP BEHAVIOUR OF THE Ti-6Al-4V ALLOY AT 500°C WITH ATMOSPHERE CONTROLLING

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The search for alloys with improved high-temperature specific strength and creep-resistance properties for aerospace applications has led in the last decades to sustained research activities to develop new alloys and/or improve existing ones. A substantial part of these activities has been devoted to titanium alloys, due to their high strength-to-weight ratio. The high strength and low density of titanium and its alloys have from the first ensured a positive role for the metal in aero-engine and airframe applications. It's difficult to imagine how current levels of performance, engine power to weight ratios; airframe strength; aircraft speed and range and other critical factors could be achieved without titanium. The titanium affinity by oxygen is one of the main factors that limit the application of their alloys as structural materials at high temperatures. The objective of this work was to evaluate the creep behavior of the Ti-6Al-4V alloy in controlled atmospheres, focusing on the determination of the experimental parameters related to the primary and secondary creep states. Constant load creep tests were conducted with Ti-6Al-4V alloy in air and in nitrogen atmosphere at 500°C. When the Ti-6Al-4V was tested in nitrogen atmosphere the effect of the oxidation was smaller and the behavior of the creep curves showed that the life time was better in atmosphere not so oxidant, there was an increasing of ductility of material (final strain) and life time.

- G – P024 DEFORMATION AND FRACTURE BEHAVIOR OF POLYPROPYLENE-ETHYLENE VINYL ALCOHOL BLENDS UNDER DIFFERENT LOADING CONDITIONS
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In this work the deformation and fracture behavior of PP/EVOH blends compatibilized with ionomer Zn²⁺ under different loading conditions was investigated. Uniaxial tensile tests and fracture experiments were performed for neat polypropylene and for 10 wt.% and 20 wt.% EVOH blends with different ionomer content. The addition of EVOH copolymer to PP led to an increase in Young's modulus whereas yield strength was found to decrease with the EVOH content as a consequence of the higher stiffness of EVOH and the poor interfacial adhesion between PP and EVOH, respectively. Furthermore, under quasi-static conditions the incorporation of EVOH to PP promoted stable crack growth. Neat PP displayed non-linear load-displacement behavior with some amount of slow crack growth preceding unstable brittle fracture whereas, most PP/EVOH blends exhibited "pseudo stable" fracture characterized by uncontrollable slow crack growth. All blends exhibited lower resistance to crack initiation than PP while fracture propagation resistance was significantly improved. Higher level of compatibilization in 10 wt.% EVOH blends led to better resistance to crack initiation. On the other hand, 20 wt.% EVOH blends with ionomer content lower or equal to 2 % showed completely stable crack growth. Therefore, quasi-static J-R curves and valid plane strain fracture toughness values could also be determined for these blends. Finally under high strain rate, all blends displayed brittle fracture characterized by linear

- G – P025 COLD PLASMA TREATMENTS PET FIBERS
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Composite materials are used in a wide variety of applications because of their higher specific properties. Mechanical strength of polyethylene terephthalate (PET) and polymethyl methacrylate (PMMA) matrix composites was studied, with particular interest in the effect of oxygen and argon plasma treated fiber on composites performance. PET fibers were treated in an internal parallel plate cold plasma reactor, using oxygen and argon gas. The excitation frequency was 13,56 MHz; the power of the electrical field 50 W; the pressure was set to 0,4 mbar and the treatment times were 5 s, 20 s, 30 s and 100 s. Oxygen and argon plasma were found to promote both mechanical keying by sputtering and etching on the surface and increasing fiber roughness. Mechanical strength modifications of PET fiber were evaluated by single fiber test and the fiber/resin adhesion, by pull-out test of the treated and untreated PET monofilaments. The contact angle measured was performed to show PET fiber surface energy growth as a consequence of plasma treatment. SEM was carried out to fiber surface analysis. Results obtained showed that cold plasma causes an increase in the PET/PMMA composites adhesion.

- G – P026 DUCTILE TO BRITTLE TRANSITION OF FERRITIC STEELS: COMPARISON OF DIFFERENT METHODS FOR A LOWER BOUND DETERMINATION
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The determination of a characteristic fracture toughness value for ferritic steels in the ductile to brittle transition regime becomes difficult due to the scatter in results. Some proposals available in the literature, based on statistical considerations, have been proposed to determine a lower bound toughness. The ability of some of these methods to predict a technological lower bound value is studied in the present work. The analyzed methods were the Master Curve, the SINTAP fracture toughness estimation procedure, the Sprödzone method, and proposals of Heerens et al. and Landes et al. The lower bound value obtained as P=3% using the Weibull distribution is also analyzed. The effect of different criteria for data censoring is also studied. Data from the literature, obtained from international Round Robins, and our own results were applied to this purpose. Pros and cons of all methods' predictions are weighed in this work. Based upon this analysis, the Sprödzone Method seems to be the best at predicting a Lower Bound value in the transition regime.

- G – P027 **MULTIFRACTAL ANALYSIS OF FRACTURE SURFACE FOR Al 7475**
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A possible correlation between fracture toughness and fractographic behavior of Al 7475 aircraft alloy is investigated. Compact tension specimens have been machined for a series of thickness values, to promote a significant change in fracture toughness. After mechanical testing, according to ASTM E1820-99a, fracture surfaces have been quantitatively investigated through 3-D reconstruction from stacks of successively focused images by using a light microscope. This method is known as “extended focus” or “depth from focus” and provides two outputs: a completely focused surface image and an elevation map with 1 μm vertical resolution. Elevation maps have been generated for three regions from each specimen: at center and at the half distance from center to each lateral edge. Multifractal analysis was done using the projective covering method (PCM). It has not been found any significant correlation between fractal values and fracture toughness evolution with specimen thickness, but the fractal character seems to be dependent on a fixed scale limit that should be related to microstructure.

- G – P028 **PSEUDOELASTICITY IN THE 2H-18R2 MARTENSITIC TRANSFORMATION**
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The pseudoelastic effect in martensitic transformations has attracted the interest of many researchers because of the potential applications in civil engineering as damping systems. The pseudoelasticity arises when the austenite-martensite transformation is induced by tensile stress above the M_s temperature. The transformation stresses increase linearly with temperature, which could be a great disadvantage for many applications. In this work we analyze a pseudoelastic effect, which was found in the 2H-18R2 martensite to martensite transformation in Cu-Zn-Al single crystals. The 2H-18R2 stress-strain closed cycles show a high hysteresis, which is around 150 MPa. After aging the 2H martensite, the transformation proceeds at nearly constant stress on loading and unloading, and in addition the transformation stresses are independent on the working temperature. Thus, this temperature independent pseudoelastic effect offers a new property for particular applications in devices. So far, the working temperature in this alloy extends at least from 220 K to 320 K. The large hysteresis is also an important parameter for damping systems. It is suggested that this hysteresis arises from the mechanism of the 2H-18R2 transformations: one phase grows into the other by the movement of partial dislocations on the closed packed planes. A possible mechanism for the dislocation generation is proposed here, which is based on the observed defect structure.