Prof. Noam Eliaz – Scientific and Technological Accomplishments (as of July 1st, 2019)

Prof. Eliaz' research is multidisciplinary and of broad spectrum, encompassing electrodeposition and electroless plating of special alloys (mainly, rhenium- and tungsten-based), electrochemically-assisted deposition of calcium phosphate coatings for dental and orthopedic implants, Bio-Ferrography, hydrogen behavior in metals, corrosion, materials durability in Space environment, failure analysis, and Additive Manufacturing (3D Printing). His most noticeable scientific and technological accomplishments are summarized below.

Electrocrystallization of calcium phosphate (CaP) coatings for orthopedic and dental implants

Since 2002 Eliaz has been conducting a very thorough R&D work on electrocrystallization of hydroxyapatite (HAp) and other CaP coatings for dental and orthopedic implants. This work has combined fundamental *in situ*, real-time studies of the electrochemical reactions and the nucleation and growth processes with the applied aspects of corrosion resistance, interaction with osteoblasts and *S. aureus* bacteria *in vitro*, and osseointegration *in vivo*. The coatings that he has developed are more biomimetic than the commercially available plasma sprayed (PS) coatings, provide enhanced osseointegration, have substrate/coating adhesion strength which satisfies the requirement of the FDA, have shown 1/3 occurrences of delamination *in vivo* compared to PS-coated implants, can be applied on porous metal scaffolds and non-line-of-site surfaces, and can be prepared under near-physiological conditions – thus allowing incorporation of collagens, antibiotics, growth factors, etc. These novel coatings are considered as a significant breakthrough. Being perceived as one of the leaders in this area worldwide, he won the Dan David scholarship for young researchers, was nominated as a JSPS visiting Fellow, and was invited to edit two volumes (52 & 53) in the reputed *Modern Aspects of Electrochemistry* book series, entitled *Applications of Electrochemistry and Nanotechnology in Biology and Medicine* (Springer). Six of his journal articles in this area have gained more than 100 citations each (Google Scholar), including an invited review article from 2017 (*Materials*) that has gained 103 citations and was highlighted as an issue cover. A CaP coating developed by Eliaz was licensed to an international dental implants company (SGS Dental Implant Ltd.), and he has led the scale-up process in Israel and the preparation for US FDA approval, as the Chief Scientist of this company.

Electrodeposition and electroless plating of special alloys

Eliaz' pioneering work (with Prof. Eliezer Gileadi) on rhenium and tungsten alloy deposition has shed light on the fundamental mechanisms and reactions, the initial stages of deposition, but also on applied aspects such as optimization of the bath chemistry and plating conditions, pulse plating, material characterization, and deposition on substrates such as carbon-carbon composites and dielectrics towards specific applications. For example, they studied the initial stages (i.e., at 0.05 to 60 s) of Re-Ni and Re-Co electrodeposition. It was concluded that the induced codeposition is a catalytic process, occurring on the surface by simultaneous reduction of ReO_4^- and $NiCit^-$, which influence each other by weak ionic interaction. The Electrochemical Society (ECS) found the first article that Eliaz et al. published in this area to be of high novelty, quality and potential impact, and selected it to be its first ever open-access article in *JECS* (2014). Eliaz et al. were also the first to synthesize rhenium-based nanostructures from an aqueous solution (self-supported Re-Ni nanowires with a core-shell structure). The results reported an *Electrochim. Acta* article served as a basis for a patent (US Patent 9,309,113 B2, 2016). Two of his former postdoctoral scholars working on Re electrodeposition have transformed into independent faculty, one in Israel (Rosen) and one in China (Wu). Eliaz and Gileadi also published an invited chapter in Vol. 42 (2008) of the eminent book series *Modern Aspects of Electrochemistry*, entitled "Induced codeposition of alloys of tungsten, molybdenum and rhenium with transition metals." This chapter has gained 126 citations according to Google Scholar. His paper (with Gileadi) on the synthesis and characterization of nickel-tungsten alloys by electrodeposition (Eliaz et al., *Electrochim. Acta*, **50**, 2005, 2893) has accumulated 208 citations and has been considered as "one of the best papers in this field published in the last 20 years." A third former postdoctoral scholar of him working on W electrodeposition (Sridhar) is now an independent faculty in India. Finally, Eliaz authored with Gileadi the 2nd edition of the textbook *Physical Electrochemistry: Fundamentals, Techniques, and Applications* – the bestselling textbook in Physical Electrochemistry (Wiley-VCH, 2019). Among others, he totally rewrote and expanded the last four chapters in the book: corrosion (which is now used as a central reference in his undergraduate compulsory course Corrosion Engineering), electrochemical deposition, electrochemical nanotechnology, and energy conversion and storage.

New Applications of Ferrography and Bio-Ferrography

Eliaz played a pioneering role in mastering the technology of Bio-Ferrography and extending its applications to new, fascinating, horizons. He thus extended the use of Ferrography, a condition monitoring technique used by the Israel Air Force (IAF) to monitor the health of helicopter assemblies. He changed the paradigm that Ferrography is adequate only for condition monitoring and failure analysis of close-loop oil systems. The results of this research were published in *Tribol. Lett.* (2009), and the technology that Eliaz developed with his student has been implemented by the IAF and by some foreign aircrafts. Another breakthrough of his is the specific magnetic isolation of bone, cartilage, circulating tumor cells and synthetic polymer particles by means of Bio-Ferrography and their characterization for early diagnostics of osteoarthritis and cancer, evaluation of the efficacy of drug treatment, or monitoring the wear of artificial joints. In addition, he was the first to demonstrate the applicability of Bio-Ferrography for isolation of nanoparticles. These contributions were recognized in 2010, when the use of Ferrography in condition monitoring was selected as having the 2nd highest impact on the IAF among all engineering projects carried out in the materials area during 60 years. In addition, a former M.Sc. and Ph.D. student of him (Ofer Levi) won in 2012 an Israeli military decoration – The Chief of Staff Medal of Appreciation. Eliaz was also the first to use Bio-Ferrography for evaluation of a new implant design (*Acta Biomater.*, 2010). Polycarbonate-urethane (PCU) was found to offer a substantial advantage over traditional bearing materials (such as ultrahigh-molecular-weight-polyethylene), not only in its low wear rate, but also in its osteolytic potential. Consequently, the US FDA approved the use of the novel implants of Active Implants, Inc. The above contributions of Eliaz have significant impact on healthcare, flight safety and several industries. He has actually became the leader of this field worldwide. Therefore, he was invited by ASM International to revised and update the chapter entitled in 'Wear particle analysis' in the 2017 edition of Vol. 18 in the reputed ASM Handbook series. Eliaz is the first ever contributor to the ASM Handbook series with an Israeli affiliation.

Corrosion in Different Environments and Failure Analysis

The significant contributions of Eliaz to Israeli defense organizations include the evaluation of advanced Polyimide-POSS nanocomposites for durability in Space (in collaboration with the Space Environment Section at Soreq NRC) and the study of hydrogen behavior in Custom 465® precipitation hardened stainless steel. The novelty and quality of the latter was recognized by the 2nd place Poster Prize at the annual EBSD meeting of the Royal Microscopical Society (Oxford

University, 2017), 1st place Poster Prize in Materials Science at The Golden Jubilee Annual Meeting of the Israel Society for Microscopy (2016), and the 1st place Poster Award at the annual meeting for presentation of projects in the areas of materials, chemistry and engineering that are carried out with funding from the Israel Atomic Energy Commission (2011), which his Ph.D. student (Sigalit Ifergane) won. In addition, in 2004-5 he was one of two principal investigators of a successful large-scale failure analysis (for the Israeli Navy) of cracking in the upper decks of Saar 5 missile boats. Based on a comparison of data from simulated tensile tests in air, tensile tests in sea water, accelerated stress corrosion cracking (SCC) experiments in sea water, and fatigue in air and in sea water (corrosion fatigue) to typical surface morphologies of cracks on deck, it was concluded that SCC was the failure mechanism. Finite element analyses and strain gage measurements on deck revealed the presence of very high residual stresses associated with poor welds. The solution involved the use of patches made of composite materials, which were especially designed by the Israel Aircraft Industry and the Fracture Mechanics lab at TAU. In a 2008 article in *Corros. Sci.*, Eliaz et al. proved by Secondary Ion Mass Spectrometry (SIMS) and a newly suggested data analysis the paradigm (which is often stated in textbooks) that since the hydrogen atom is small and its mobility is high – it will not be detected near fracture surfaces following failure – to be wrong. The process of delayed failure due to hydrogen embrittlement after electroplating was redefined in terms of trapping and the associated potential energy barrier, instead of irreversible damage that occurs within the substrate during electroplating (the latter is the explanation in ASTM standards). This finding is of great importance in quality control and failure analysis, and can explain behaviors which could not be explained before. The test procedure developed in this work is already used routinely by the IAF. Eliaz also led the failure analysis of cementless femoral stems that had fractured *in vivo* at the junction of modular revision hip arthroplasty systems (ZMR®, Zimmer, Inc.). The results with recommendation on preventative measures were published in *J. Bone Joint Surg. Am. Vol.* in 2011. Consequently, Zimmer had to redesign this prosthesis. In 2001 Eliaz et al. published in *Corros. Sci.* the first ever corrosion study of a biomaterial prepared by 3D Printing. The novelty and potential impact of this work was recognized by the T.P. Hoar Award for the best paper published in this journal during 2001. Eliaz was a key participant in a project that was selected in 2010 as having the 3rd highest impact on the IAF among all engineering projects carried out in the materials area during 60 years – the analysis of turbine seals in General Electric's F110 engines in F-16 airplanes that failed around the globe (AW&ST, 2014). His international reputation in the areas of corrosion and failure analysis is reflected also from a special issue of *Corros. Rev.* on 'Biomaterials Corrosion' that he edited with Dr. Mudali (2003), the book Degradation of Implant Materials that he edited (Springer, 2012), his nomination as a Fellow of NACE International (2012), and the Technical Achievement Award by NACE International that he won (2014). The citation of the latter summarizes nicely: "For outstanding achievements in corrosion research, engineering and education, with key contributions in electrodeposition of special materials, biomaterials corrosion, and failure analysis in the aircraft, space, medical device, nuclear power generation, and naval industries." Eliaz was the first Israeli to receive any NACE International award.