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Biography of the Prager Medalist: Professor George Weng

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“For his outstanding research contributions in theoretical solid mechanics”
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Professor George Weng received his B.S. from National Taiwan University in Mechanical Engineering in 1967 and his Ph.D. from Yale in Engineering and Applied Science in 1974. Prior to receiving his degree, he spent one year at Delft University of Technology as a Research Fellow with Professor Peter Jongenburger from 1973 to 1974, another year as a Postdoc with Professor T. H. Lin of UCLA from 1975 to 1976. After one year of work at General Motors Research Laboratories, he joined Rutgers as an Assistant Professor in 1977. He was promoted to an Associate Professor in 1980, a Full Professor in 1984, and a Distinguished Professor (previously called Professor II) in 1992. The award of Prager Medal gave his former Ph.D. students, colleagues at Rutgers, and friends elsewhere much pleasure.

Weng started his professional life as a graduate student at Yale, working on the theory of yield surface based on dislocation mechanics under the supervision of Professor Aris Phillips. Phillips was a noted scientist

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in experimental plasticity. For many years, he had explored the nature of yield surface and hardening laws and reported many ground-breaking observations. His instruction to this young man was “we need some physical theories to explain all of these experiments”. With it, he began to embark on a long journey of micromechanics study in solids.

Later, he used to tell his own graduate students that Phillips was a very liberal professor, that he gave him a world of freedom to do research and rarely checked his progress. This happened to suit him very well. He also said that occasionally, he would work at the circulation desk of the Engineering Library in the evening and read many books and articles that later turned out to be very useful. At that time, the theory of dislocations was an active area of research in materials science and yield surface was also a major focus in plasticity, but there was little or no connection between the two. Weng quickly recognized the importance of bringing the underlying dislocation behavior up to the continuum level, to provide the physical foundation for the properties of yield surfaces. The hardening rules of metals were dominated by Taylor’s isotropic hardening, Prager’s kinematic hardening, and Ziegler’s modification, but no experimental data were reported to substantiate their validity. Phillips’ experiments consistently demonstrated that, on top of the rigid body motion implied in kinematic hardening, the shape of the yield surface also tended to distort, with the front portion showing an inflated shape and the back a deflated one. Based on dislocation mechanics, he started to develop his own active and latent hardening laws for the slip systems of the constituent grains and then translated them up to the polycrystal level. In due course, he was able to provide the physical foundation for Phillips’ extensive experiments. In 1974, he submitted his Ph.D. thesis entitled: *The Investigation of Yield Surface by Dislocation Mechanics*. From his thesis also grew several other papers on the physical origins of hardening laws in crystal plasticity. One of them was “Kinematic hardening rule in single crystals” published in 1979 that was akin to Prager’s kinematic hardening rule, and another was “Anisotropic hardening in single crystals and the plasticity of polycrystals” in 1987, in memory of Aris Phillips.

This early work on the transition from dislocation theory to continuum plasticity quickly led to his study of single crystals versus polycrystals. From 1980, he began to present various self-consistent schemes for the single-to-polycrystal transition for the rate-independent and rate-dependent plasticity. These include the time-dependent creep, stress relaxation, unified plastic-creep deformation, and influence of fatigue stress, and he also developed a self-consistent model for dual-phase polycrystals, in which each phase was capable of undergoing crystallographic slips in its own constituent grains. This series of works spanned the period from 1980 to 1985.

The study on the self-consistent schemes of single crystals versus polycrystals in turn directed his attention to the broader issue of micromechanics of composites. He said in his early days he drew considerable inspirations from the writings of Eshelby, Hill, Kroner, Hashin and Shtrikman, Willis, Walpole, and Mura. His learning from Hill was more direct—he maintained a long stretch of communications with Hill for over two decades. Subsequently, the works of Christensen, Dvorak, and Nemat-Nasser also had a direct impact. The originality of their works proved to have far-reaching influence on his contributions to the theory of inclusions and elastic properties of reinforced solids. The study during this period also led to his discovery of the connection between Mori-Tanaka’s theory and the Hashin-Shtrikman-Walpole bounds. Some of the papers he wrote along this line are now widely known. In particular, the two papers he wrote in 1984 and 1990 have proved to have some fundamental importance to the foundation of the Mori-Tanaka method, and another two, jointly written with his Ph.D. student G.P. Tandon in 1984 and 1986, are known to have some particular value for applications.

Based on his study of elastic properties, he then moved on to the plasticity of particle-reinforced composites. In order to study this nonlinear problem, he introduced the concept of secant moduli into the elastic framework in 1988. The usefulness of the secant moduli also became evident in the study of dual-phase metals, and in the formulation of plastic potential and yield function of porous materials and composites that he subsequently carried out with his Ph.D. student Y.P. Qiu. In the meantime, he also started to work on the properties of viscoelastic composites with his other Ph.D. student, Y.M. Wang. The concept of secant moduli for rate-independent plasticity was soon extended into secant viscosity for the rate-dependent viscoplasticity and creep with his Ph.D. student J. Li. Both the secant moduli and the secant viscosity approaches have also proven to have wide applicability for the study of rate-independent and rate-dependent plastic behavior of particle-reinforced solids.

While the volume concentration of particles or inclusions tends to remain constant in ordinary composites, it will evolve during phase transitions. The issue of volume change was initially taken up with his Ph.D. student H. H. Pan around 1992, to study transformation toughening. Subsequently, in 1994, he and his other Ph.D. student A. Bhattacharyya, started to investigate the problem of phase transition in a ductile system, with an eye on the behavior of TRIP (transformation-induced plasticity) steels. They developed an energy criterion based on Gibbs free energy to calculate the evolution of martensite plates from the ductile austenite matrix

during the martensitic transformation. With it, they were able to demonstrate how the total nonlinear strain was attributed to two different sources, one from the traditional plastic strain and the other from the phase transformation strain. The overall stress–strain curve then exhibits the widely observed sigmoidal shape, a common phenomenon that had never been explained from the micromechanics perspective.

Around this time, the study of shape memory alloys (SMAs) was very active in the US, and challenge to the understanding of multifunctional materials also began to emerge. In 1997, he began to extend the nonlinear theory he developed for TRIP steels to study the phase transition in SMAs with his Ph.D. student Z. K. Lu. Based on the developed Gibbs free energy for a dual-phase system, the concepts of thermodynamic driving force and kinetic equations were soon developed and applied to explain and predict the pseudoelastic behavior and shape memory effects of SMA single crystals, polycrystals, and SMA-reinforced composites. Though his number of publications in SMAs was not high, his 1997 and 1998 papers are known to provide a solid foundation for the study of inclusion-based phase transition in thermoelastic systems.

In 1999, he and J. Li began to extend the principle of phase transition in SMAs to ferroelectric crystals. With the introduction of electromechanical coupling, spontaneous strain, and spontaneous polarization, they formulated a micromechanics-based thermodynamics theory for the domain switch. Soon after and jointly with his Ph.D. student, Y. Su, he began to extend the framework of domain switch to phase transition in ferroelectric crystals and brought it from the grain level to the level of polycrystalline aggregates. In this series of works, the issues of shift of Curie temperature, influence of pressure and electric field, formation of double and triple hysteresis, and change of dielectric constant during phase transition, had all been accounted for. His contributions have indeed added a new dimension to our knowledge of ferroelectric phenomena.

With the emergence of nanocrystalline materials, he began to develop the micromechanics theory with his Postdoc, Bing Jiang, for this class of new materials around 2003 and used it to study the grain-size dependence—or the Hall-Petch and the inverse Hall-Petch relations—of their yield strength. The objective was to find the optimal grain size at which the material could have the maximum yield strength. The study hinged upon the delicate competition of grain-size hardening and grain-boundary softening with the decrease in grain size. His works represented a drastic departure from the then widely adopted rule of mixture approach in the materials community. The focus of rate-independent plasticity in his early papers was soon extended to the rate-dependent viscoplasticity and creep to study the grain-size dependence, strain-rate sensitivity, and activation volume with J. Li and graduate student P. Barai. His study on nanocrystalline materials spanned the period of 2003–2010. Both his rate-independent and rate-dependent studies have brought significant new physical insights into the competition of grain interiors, GB zone, and grain-boundary sliding.

At the same time, he also became very interested in the mechanical and transport properties of carbon nanotube-based composites. Carbon nanotubes are known to have exceptional elastic stiffness, and extremely high thermal and electrical conductivities, but various experiments on CNT-based composites continued to show that the measured effective properties could not reach the expected levels of effective properties. His work with P. Barai in 2011 on the plasticity of carbon nanotube-reinforced composite pointed out that, while CNTs are in general a very effective strengthening agent, both CNT agglomerations and the imperfect interface condition have proven to be two key detrimental factors that limited the potential of their plastic strength. His other work on CNT-based thermal conductivity with Prof. T. Chen in 2005 pointed out that the Kapitza interfacial contact and the poor tube-end transport were the two main sources that limit the attainment of the theoretical values. Over the past two years, he and Prof. S. Meguid have jointly studied the effective electrical conductivity of CNT-based polymer composites by looking into the issues of percolation threshold and electron tunneling resistance between CNT junctions. Some exciting results have been obtained and reported in the literature.

At present, his focus is on the micromechanics and phase fields of multiferroic composites for strong magnetoelectric coupling. He continues to pursue the issues of percolation theory and network formation for the transport properties of CNT- and graphene-based polymer composites.

Over the past two decades, Weng was fortunate enough to have several very able visiting scientists to come to Rutgers. These include Prof. Y. H. Zhao from Dalian, Prof. T. Sakaki from Tokyo, Prof. Cewen Nan from Tsinghua, Prof. Wenfang Li from SCUT, and Prof. Chunyu Li from Shijiazhuang. Many of them are now very well-established scientists. He also had the fortune to work with Prof. Gengkai Hu of BIT and Prof. Keichiro Tohgo of Shizuoka. These and many of his other Ph.D. students have all greatly contributed to his research activities.

In addition to his scholarly outputs, Weng has also contributed to the field of solid mechanics in several other ways. He has been an Editor of *Acta Mechanica* since 1985 and was the Technical Editor of *ASME Journal of Engineering Materials and Technology* from 1992 to 1997. At present, he also serves on the Edi-

torial or Advisory Boards of *Mechanics of Materials*, *International Journal of Mechanics and Materials in Design*, *Journal of Mechanical Behavior of Materials*, and *Acta Mechanica Solida Sinica*. Previously, he was on the Boards of *International Journal of Plasticity*, *JSME International Journal Series A: Solid Mechanics and Materials Engineering*, and *Mechanics of Advanced Materials and Structures*, among others. He was Chairman of the ASME Materials Division Executive Committee from 1993 to 1994 and Chairman of the ASME Materials Division 75th Anniversary Diamond Jubilee Lectures in San Francisco in 1995. He has given several opening and plenary lectures and many keynote lectures at national and international conferences, and has edited several special volumes and books. Weng is also a Fellow of the American Society of Mechanical Engineers, a Fellow of the American Academy of Mechanics, and a Life Member of the Society of Engineering Science.

His Prager Medal citation appropriately reads: “in recognition of his fundamental contributions to the theory of inclusions, micromechanics of composites, multifunctional materials, and coupled behavior in solids”. Over the past three decades, his research interests have continued to evolve and are still evolving. We fully expect that his continued pursuit of engineering science will bring to us yet another level of understanding to solid mechanics.

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