Unified Micromechanics Theory of Composites (UMTC) - New Philosophy of Micromechanics

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UMTC proposed is developed for analyses of composite materials (CMs) of either matrix random (statistically homogeneous or inhomogeneous probability descriptors), periodic, or deterministic (neither random nor periodic) structures, endowed with local, weakly nonlocal (higher-grade, higher-order, or micromorphic models), strongly nonlocal (strain-type or displacement-type, peridynamics [1, 2]), or multiphysics phase properties.

It is not only a matter of generality—which may sometimes appear to be an end in itselfbut rather of the new opportunities that were previously unimaginable.

So, the first foundation of micromechanics based on effective field hypothesis (EFH) was developed by Poisson, Faraday, Mossotti, Clausius, Lorenz, and Maxwell (1824–1879, see [1]). A second foundation [1] (called also Computational Analytical Micromechanics, CAM) emerged from new General Integral Equations (GIEs) that generalize Rayleigh's GIE (1892). New GIEs eliminate the need for EFH, Green's functions, linearity of GIEs [3], and even constitutive descriptions of phases (see Chapter 7 in [1]). CAM represents the first radical shift in micromechanics since Rayleigh's (1892) work work more than 130 years ago.

The Unified Micromechanics Theory of Composites (UMTC [6]) represents a profound conceptual shift in micromechanics. It introduces three genuinely transformative ideas that break with the traditional framework: (i) an exact Additive General Integral Equations (AGIE), valid for CMs of arbitrary structure and phase behavior under body forces with compact support (BFCS)-a fundamentally new training parameter that reshapes how micro–macro transitions are learned [5-9]; (ii) a radically new conception of the Representative Volume Element (RVE [4, 5]), no longer a fixed geometric entity but an emergent construct governed by the physics of locale fields; and (iii) a new effective dataset (***ED***, [3-8]), extending far beyond the classical notion of effective moduli, which is naturally selected by this RVE and inherently free from edge effects, boundary layers, and finite-size artifacts. z. Consequently, classical frameworks of Analytical Micromechanics (based on GIEs [1] and do not use direct numerical simulation, DNS) and Computational Micromechanics (exploited DNS, such as asymptotic expansions and computational homogenization) reach the limits of their applicability (see [5]). The implementation of BFCS reduces the AGIE–CAM formulation for media with arbitrary microstructures—random, periodic, or deterministic—defined over an infinite domain to a substantially simplified problem involving only a limited number of inclusions within a finite-sized sample. This reduced problem is computationally tractable using any standard numerical technique, including finite element analysis (FEA), FFT-based methods [6], and boundary or volume integral equation approaches [6, 7]. The fundamental interrelations between GIE and AGIE are rigorously established. Remarkably, both the GIE and the AGIE arise from the same historically celebrated—but fundamentally incorrect—equation, yet they branch into two profoundly different and foundational directions in micromechanics. While their solution operators appear formally similar, they embody fundamentally different physical meanings and methodological philosophies.

Through the incorporation of new ***ED*** into existing machine-learning and neural-network (ML&NN) methodologies, UMTC makes it possible to construct arbitrary, previously undefined surrogate nonlocal operators [6], thereby entirely eliminating edge, boundary-layer, and sample-size effects—barriers that are fundamentally insurmountable for standard ML&NN techniques at the nonlocal surrogate operators' estimations. A practical predictive framework of UMTC is

$$\text{BFCS} \rightarrow \text{AGIE} \rightarrow \text{RVE} \rightarrow \boldsymbol{ED} \rightarrow \text{ML\&NN} \qquad (1)$$

The concepts of AGIE, new RVE, and ***ED*** - as well as their integration into ML&NN --represent fundamentally new theoretical constructs. It is demonstrated that possible 2D or 3D examples do not provide the same level of clarity and lack of ambiguity as the 1D performed parametric analyses, which enable each of the three major concepts to be validated separately, both qualitatively and quantitatively, and in a rigorous manner [6]. To the best of the author's knowledge, these ideas have not appeared in prior publications by other authors, either individually or in combination, in their present form. The methodology (1) is designed [6] -- for the first time -- as a modular, block-based system, allowing specialists in one block to contribute without requiring expertise in the underlying details of other blocks. Furthermore, when developing joint software, each block team has the autonomy to make modifications or improvements to their block at any stage of its development, without the need to inform or disrupt the partner team. This structured approach facilitates effective collaboration while maintaining flexibility and efficiency in the overall system. In this sense, UMTC establishes not merely a new theory, but a new *philosophy* of micromechanics [6] —one that may be viewed as the most significant conceptual advance in the field in over 200 years, since the first foundation by Poisson, Faraday, Mossotti, Clausius, Lorenz, and Maxwell (1824–1879).

The first offline presentation of UMTC was delivered in my Keynote Lecture, "*Unified Micromechanics Theory of Composites* (UMTC)," at the *Conf. of American Society of Composites* in Dayton (10.06.2025) - the place where my career in the United States began at AFRL and UDRI (a short video https//wwwacademicconf/Video/Details?paperId=44102). As the author of UMTC, I feel a strong personal and professional responsibility to further develop, advance, and actively promote this new framework within the mechanics and materials community. I would be delighted to present UMTC online as part of a seminar series for any department, laboratory, or company worldwide. I warmly welcome such invitations—please contact met buryach@yahoo.com

[1]. Buryachenko VA (2022) Local and Nonlocal Micromechanics of Heterogeneous Materials. Springer, NY (1024 pp., 1711 refs.)

[2] Buryachenko V. A. (2024) Peridynamic micromechanics of composites: a critical review. *ttps://arxiv.org/abs/2402.13908v4* (109pp., 466 refs., extended version of *JPER*, **6**, 531–601).

[3]. Buryachenko V. A. (2025) Nonlinear elastic general integral equations in micromechanics of random structure composites. *Math. Mech. of Solids,* **30**, 720-744

[4] Buryachenko V. A. (2025) Critical analyses of RVE concepts in local and peridynamic micromechanics of composites. *J. Period. Nonlocal Modeling,* **7**:9. Extension: *https://arxiv.org/abs/2402.13908v5* (71pp, 336refs.)

[5]. Buryachenko V. A. (2025) Peridynamic micromechanics of periodic structure composites subjected to body force with compact support. *Math. Mech. of Solids,* **30**, https://doi.org/10.1177/108128652513790

[6]. Buryachenko V. A. (2025) Unified Micromechanics Theory of Composites. *https://arxiv.org/abs/2503.14529v2* (49pp, 540refs.)

[7]. Buryachenko V. A. (2025) New RVE concept and FFT methods in micromechanics of composites subjected to body force with compact support. *https://arxiv.org/pdf/2601.00822* (33pp., 98 refs.)

[8]. Buryachenko V. A. (2025) Additive general integral equations in thermoelastic micromechanics of composites. *https://arxiv.org/pdf/2601.00019* (42 pp., 94 refs.)

[9]. Buryachenko V. A. (2025) New RVE concept in thermoelasticity of periodic composites subjected to compact support loading. *https://arxiv.org/pdf/2601.00018* (41 pp., 85 refs.)