Preface

This book stems from my first acquaintance with Academician Victor E. Panin of the Soviet Academy of Sciences, and my daily research log that I have been keeping since then. At the end of 1990, I had the opportunity to listen to a lecture given by Acad. Panin at a meeting held in Tokyo, Japan. In this meeting, a number of delegates from the Soviet Academy of Sciences gave presentations to Japanese business people. The Acad. Panin’s lecture was on a new theory of plastic deformation that he called physical mesomechanics. Although I understood only 20%, or probably less, of his lecture, I was greatly fascinated by his enthusiastic presentation and by the physical-mesomechanical view of plastic deformation. (He was among the two or three presenters who gave the talk in English without an interpreter.) In particular, the Maxwell-type field equations that describe plastic deformation dynamics interested me greatly. At that time, my field of research was laser and spectroscopy, and I was using the Maxwell equations of electrodynamics on a daily basis. Although I did not understand the Maxwell-type field equations of physical mesomechanics in any depth necessary to comprehend the deformation dynamics behind them, I was able to understand that the equations described the translational and rotational interaction of the displacement field. With my limited knowledge of continuum mechanics, I was able to sense that material rotation and its interaction with translational displacement is important in the plastic regime, and that the Maxwell-type field equations represent that effect.

During the coffee break, I came to Acad. Panin to introduce myself and ask a number of questions about his presentation. He answered each of my questions enthusiastically. Moreover, he kindly invited me to the post-meeting banquet to be held at the USSR embassy later that day. Of course I accepted the invitation and attended the banquet where I was able to discuss with Acad. Panin a wide range of topics in strength physics and material sciences. He gave me a book written in Russian as a gift, and invited me to an international conference being held in the

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1Presently the Russian Academy of Sciences.
following summer in Tomsk, Siberia. I did not know the language at that time. I was so interested in the book that I took Russian language courses for 2 years.

In the summer of 1991, I attended the conference in Tomsk and met a group of scientists working in Acad. Panin’s group. The discussions I had with them were revolutionary to me. They explained the Maxwell-type field equations, the interaction between the translational and rotational displacement in plastic deformation, and other gauge theoretical concepts in detail. To be honest, my knowledge about gauge theories at that time was almost none. After returning home, I read a handful of books on gauge theories and got more confused. I kept reading and learned that the electromagnetic field is the gauge field that makes quantum mechanics locally symmetric. This brought me to the turning point. I started to understand the concept of gauge transformation and local symmetry. I analyzed various gauge theoretical concepts in deformation dynamics via analogy to electrodynamics. Interestingly, this exercise deepened my understanding on electrodynamics. I noticed a number of different views on Faraday’s law and Ampere’s law as the interaction between the electric and magnetic field that nature uses as a mechanism to stabilize events, e.g., prevent runaway increase of current. This, in turn, helped me consolidate the basic understanding on the gauge-field nature of plastic deformation dynamics.

As I kept deepening my understanding on the physical foundation of physical mesomechanics, I realized that the theory was much more profound than I initially thought. It was an elegant theory capable of describing plastic deformation based on pure physics, unlike most theories of plastic deformation that relies on phenomenology or mathematical models. It indicated a number of potential engineering applications as well. However, the work at that time was somewhat inclined toward the mathematical aspect of the theoretical foundation with little experimental proofs. I started to conduct experiments trying to prove various elements of the theory, such as transverse wave characteristics of displacement field in the plastic regime. To measure displacement field, I used an optical interferometric technique known as the ESPI (Electronic-Speckle Pattern Interferometry). I found several interesting phenomena that could be explained by the same physical foundation as physical mesomechanics. Through analysis of these experimental observations, especially with the help of analogy with electrodynamics, I conceived new ideas in the description of deformation dynamics such as the concept of deformation charge and its role of energy dissipation. This helped me advance the theory from the field-theoretical description of plastic deformation dynamics to a comprehensive theory of deformation and fracture based on the same theoretical foundation. To date, I have continued investigating the field theoretical dynamics of deformation using the ESPI.

As will be discussed in the following chapters, development of this theory has not been completed. I decided to put together the knowledge and information I gained so far as a book at this point for several reasons. First, recent experimental observations have convinced me of the validity of the theory. Essentially, the gauge field in deformation dynamics makes the law of linear elasticity locally symmetric. The nonlinear dynamics in the plastic regime is formulated through the potential associated with the gauge field. Second, these experimental observations and their
field theoretical interpretations demonstrate potential of engineering applications. In particular, the use of ESPI techniques allows us to visualize the deformation field as a full-field image, and along with field theoretical interpretations, it provides us with various information. For example, the use of the field theoretical criteria of plastic deformation and fracture allows us to make diagnosis of the deformation state of a given object. Third, I would like to invite specialists of different disciplines to this research for further development of the theory and applications. On the theoretical side, connections with microscopic theories are very important. At this point the theory incorporates the effect of microscopic defects that causes plastic deformation generally into the field equations via the source terms. If a specific form of the source term is provided by a microscopic theory, it is possible to describe how the microscopic defect can evolve to the final fracture under a given condition. Also, more thermodynamic argument will allow us to discuss the energy dissipation process resulting from irreversible plastic deformation more specifically. For applications, software development for visualization of displacement field in objects under deformation, especially during the transitional stage from one regime to another, e.g., from the elastic to plastic regime, will be not only an interesting application but also helps further advancement of the theory. Numerical simulations are also important for further tests of the theory and explore for new applications. Lastly, I would like to share my experience of learning the Maxwell’s formalism and the gauge theories with students. A number of electrodynamic concepts that were unclear to me when I was in the graduate school became crystal clear through this project. I would like to invite students and have them feel the beauty of field theories. In my opinion, this subject is ideal to visualize the concept of local symmetry associated with a gauge field, which is otherwise abstract and difficult to comprehend. I tried my best to portray the complicated concept with plain terms and analogies without going into mathematical details. It is also a unique case in which these concepts, which are usually discussed by scientists specialized in basic physics such as high energy or particle physics, are discussed in connection with real world applications such as nondestructive testing of metal objects. I hope that this book is helpful to people in any of these and related disciplines.

I tried my best to cite literature appropriately. If some papers or books do not receive fair credit or are not cited, I apologize.

Finally, I would like to express my sincere gratitude to a number of people. First of all, I would like to thank Acad. Victor Panin for introducing to me his beautiful paradigm of deformation dynamics and his friendship ever since. I am grateful to countless colleagues who always supported me during the development of this theory, especially Professor Cesar Sciammarella for his continuous encouragement and precious discussions. Through my learning processes of gauge theories and continuum mechanics, I realized that I owe greatly to all the professors and teachers from whom I received my graduate and undergraduate trainings. Without their excellent instruction, I would have never reached the present level of understanding on the subjects. I also thank all of my friends and students who helped me with the experiments and computations that provided a number of supporting data.

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