FRACTURE OF COMPOSITE MATERIALS

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Proceedings of the Second USA-USSR Symposium,
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March 9-12, 1981

edited by

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PREFACE

The Second USA-USSR Symposium on *Fracture of Composite Materials* took place at Lehigh University, Bethlehem, Pennsylvania, during 9-12 March, 1981. This bilateral program between the U.S. and Soviet Union was organized by Professor George C. Sih of the Institute of Fracture and Solid Mechanics at Lehigh University and Dr. Vitauts P. Tamuzs of the Institute of Polymer Mechanics of the Academy of Sciences of the Latvian SSR in Riga. The First Symposium was held in 1978 at Jurmala near the coast of Riga Bay.

The primary reasons for initiating this series of Symposia were to disseminate present knowledge, to promote interchange of ideas, and to stimulate additional studies on the development of composite materials between the U.S. and USSR. Both countries have a vested interest in developing the capability to assess and utilize the attractive mechanical properties of composites so that they can be tailor-made to meet specific design requirements. Despite the increasing number of published papers and articles, there is no communication more effective than on a person-to-person basis. It is with this objective in mind that a small group of engineers and scientists from the U.S. and USSR have planned to meet every two years to report recent progress on composite material research. The size of this group is approximately sixty (60) participants. The presentation involves about forty (40) technical papers which are published in a volume. The first Proceedings are already in print and can be obtained from Sijthoff and Noordhoff located in Alphen aan den Rijn, The Netherlands. The Russian version has been printed by the publishing house, "Zinātne", in Riga, USSR.

The ten members of the Soviet delegation at the Symposium were headed by the corresponding member of the USSR Academy of Sciences, Professor V. V. Bolotin. The Executive Secretary of the delegation was Professor V. P. Tamuzs. A U.S.A. organizing committee was formed to select topics for discussion and speakers. The members were:

G. C. Sih (Chairman)
C. W. Smith
T. T. Chiao

S. C. Chou
R. E. Rowlands
C. C. Chamis

The main theme of the Symposium is the fracture of composite materials possessing geometric discontinuities or inherent material defects. Because of the complexity of composite fracture behavior which is characteristic of heterogeneous materials, many of the analyses have to resort to simplifying assumptions. Generally speaking, the *basic concept* of linear elastic fracture mechanics is applicable when a composite system exhibits brittle fracture behavior. This, however, does not imply that all composites can be characterized by the single crack critical stress intensity factor formula $K_{Ic} = \sigma\sqrt{\pi a}$ or the equivalent of G_{Ic} , often referred to as the Griffith theory. It should be remembered that the Griffith equation applies only to self-similar cracks and assumes that all the released energy is converted to the extension of a single crack. These idealized assumptions obviously deviate far from the fracture modes in composites which may involve fiber breaking, matrix cracking, debonding, etc. The burden is on the practitioner to apply fracture mechanics correctly and to perform the appropriate stress analysis. The concept of fracture toughness when applied to composites should be interpreted with care. It applies strictly to a homoge-

neous isotropic material and is considered to be independent of loading and crack geometry. There is little to be gained if the measured fracture toughness parameter changes with the direction of loading and/or fiber reinforcement. For in that case, information on the failure load will suffice. The objective is to predict the allowable load on a composite from a knowledge of the toughness values of its constituents.

For unidirectional composites in which cracking occurs predominantly in the matrix, it suffices to know the fracture toughness of the matrix for predicting failure. In the cross-ply laminates, material damage consists of delamination as well as cracking and analytical modeling of the damage zones becomes difficult. Oversimplifications can significantly distort the physical interpretation of the results. Experimental studies on delamination in laboratory specimens containing free edges on all sides may not represent the condition in structure application. It is essential that the fracture modes in the actual structures be realistically simulated in the laboratory specimens.

Another area of major concern is a knowledge of the mechanical properties of the constituents from which the overall mechanical response of the composite can be determined. Such an approach encounters enormous difficulties and uncertainties because the properties of the fiber-to-matrix interface cannot be easily assessed. The dependence of fiber strength on initial defects is another source of difficulty. Stochastic models for estimating the strength of unidirectional fiber composites are proposed. Considerations are given to composite damage in the form of fiber breakage, debonding, etc. Since the main life of composites up to fracture is of dispersed nature, the statistical models including both the dispersed stage of damage accumulation and the transition to macro-crack propagation play an important role in formulating the fracture prediction methods.

Non-destructive evaluation of material damage can greatly assist the understanding of how composites respond to mechanical loading. Parameters representing inherent material properties need to be distinguished from those describing apparent changes in material behavior caused by physical damage such as defects or cracks. This area deserves the utmost attention in future research, both in theory and experiment. Lacking in particular is the predictive capability of composite failure.

Clearly, this Second USA-USSR Symposium did not cover the whole problem of composite fracture. Each of the topics discussed could be the topic of one or several symposia. Nevertheless, as a forum for reporting new findings, exchanging ideas, establishing directions of future research and making new friends, this Symposium has served well.

A number of the U.S. organizing committee members accompanied the Soviet delegates on a one-day excursion to Atlantic City. The theory of stochastic processes was applied once more to Blackjack, this time with less success. The bus ride, however, provided an additional opportunity to discuss technical problems.

The organizing committee wishes to acknowledge all those who contributed to the presentation and preparation of technical papers. Their efforts have made the Symposium a great success. Special thanks are also due to Robert Bolton, David Chu, Robert Kolka, Michael Lieu, Erdogan Madenci, Peter Matic, Thomas

Moyer, Spence Reid and Stone Shih who were responsible for making the detailed arrangements. Mrs. Barbara DeLazaro and Mrs. Constance Weaver spent a great deal of their time organizing and coordinating numerous activities associated with the Symposium. Their assistance in typing the manuscripts is also gratefully acknowledged. Acknowledgements also go to Valentina Kiseljova and Marite Smalka who have contributed to the preparation of the Soviet papers.

March, 1981
Lehigh University, USA
Institute of Polymer Mechanics, USSR

G. C. Sih
V. P. Tamuzs
Editors

REMARKS ON SYMPOSIUM SERIES

The first USSR-USA Symposium on Fracture of Composite Materials was held at the Baltic resort site of Jurmala, USSR, during September of 1978. This second Symposium is being held at Lehigh University in the United States of America. The topic on the fracture mechanics of composites is chosen for the USSR-USA scientific cooperation because of the important role composites play in the design of modern engineering structures. Composites offer high strength in addition to low weight. The manufacture of composites requires comparatively low labor and waste, and is desirable as far as pollution is concerned when compared with steel making. Composite structures are destined for many future applications.

There is no doubt in my mind that the topic of this Symposium is also valuable from the scientific point of view. I personally believe that the "mechanics of fracture" and "mechanics of composites" are the two foremost branches of modern applied mechanics. Fracture of composite materials includes a combination of the two and should pave the way for the development of applied mechanics.

The choice of holding this Symposium at Lehigh University is also appropriate for the School of Engineering of this University is associated with a number of renowned researchers and scholars in the field of mechanics of fracture. Among them are Professor G. R. Irwin who taught at Lehigh for many years and Professor P. C. Paris who is a graduate of this University. Professors G. C. Sih, R. S. Rivlin and F. Erdogan are still engaged in research and teaching at Lehigh. These colleagues have made substantial contributions to the mechanics of fracture.

The first USSR-USA Symposium on Fracture of Composite Materials was most successful as evidenced by the 1979 Proceedings published both in Russian and English. The Proceedings represent one of the most up-to-date comprehensive studies on the mechanics of fracture of composites. It also provided an excellent opportunity for the Soviet and American scientists to exchange ideas and research findings, and to focus attention on future problems.

The success of this second Symposium is clearly demonstrated by the contents of this book which includes the progress in this field for the past two and one-half years. Among the topics covered are: development of stochastic models of fracture of composites with application to predicting the scale effects in composite structures; influence of environmental conditions on composite strength, integrity and durability; design of multilayered composite shells; and others. It is unfortunate that some of the papers presented by the American authors are not made available in written form. Many of the stimulating discussions also did not go on record.

The next USSR-USA Symposium on Fracture of Composite Materials is planned to take place in USSR. It is hoped that up to that time many new findings and achievements will be made in this interesting and rapidly developing field of applied mechanics.

March, 1981
Mechanical Engineering Research Institute
USSR Academy of Sciences

V. V. Bolotin
Head of USSR Delegation

Professor G. C. Sih, Director of Institute of Fracture and Solid Mechanics, Lehigh University, USA, addresses the audience on Fracture of Composite Materials.

Professor V. V. Bolotin, Head of USSR delegation, USSR Academy of Sciences, discusses a stochastic model of fracture of composite materials.

Technical session at the Sinclair auditorium.

Question period during the Symposium
on Fracture of Composite Materials.

Participants attending a technical session.

Question raised by Professor V. V. Panasyuk at center.

Members of the USSR delegation look over the choice of drinks.

Cocktail hour in the Neville Lounge at the University Center.

Co-Chairman, Dr. G. C. Sih, briefs on the objectives of the USA-USSR Symposium.

Banquet at the Asa Packer Dining Hall.

Dr. W. Deming Lewis, President of Lehigh University, presents a plaque to the Head of the USSR delegation, Professor V. V. Bolotin.

Professor G. C. Sih receives a plaque from Dr. V. Tamuzs (center) and Professor V. V. Bolotin with Dr. I. Knets standing by.

Members of the USA-USSR delegation on Fracture of Composite Materials.
 From left to right front row: L. V. Nikitin, G. A. Teters, C. W. Smith,
 V. Tamuzs, V. V. Bolotin, G. C. Sih, V. V. Panasyuk, E. M. Wu, S. T.
 Mileiko, V. V. Vasil'ev and back row: R. E. Rowlands, I. Knets, F. W.
 Crossman, S. C. Chou, V. K. Khlébnykov.

Group picture of the Second USA-USSR Symposium on Fracture of Composite Materials, Lehigh University, Bethlehem, Pennsylvania, March 9-12, 1981.