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Recent Developments in High Strain Rate Mechanics and Impact Behavior of Concrete

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Editors:
Eric Jacques and Mi G. Chorzepa

American Concrete Institute
Always advancing

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PREFACE

Recent Developments in High Strain Rate Mechanics and Impact Behavior of Concrete

This Symposium Volume reports on the latest developments in the field of high strain rate mechanics and behavior of concrete subject to impact loads. This effort supports the mission of ACI Committee 370 “Blast and Impact Load Effects” to develop and disseminate information on the design of concrete structures subjected to impact, as well as blast and other short-duration dynamic loads. Concrete structures can potentially be exposed to accidental and malicious impact loads during their lifetimes, including those caused by ballistic projectiles, vehicular collision, impact of debris set in motion after an explosion, falling objects during construction and floating objects during tsunamis and storm surges. Assessing the performance of concrete structures to implement cost-effective and structurally-efficient protective measures against these extreme impacting loads necessitates a fundamental understanding of the high strain rate behavior of the constituent materials and of the characteristics of the local response modes activated during the event.

This volume presents fourteen papers which provide the reader with deep insight into the state-of-the-art experimental research and cutting-edge computational approaches for concrete materials and structures subject to impact loading. Invited contributions were received from international experts from Australia, Canada, China, Czech Republic, Germany, South Korea, Switzerland, and the United States. The technical papers cover a range of cementitious materials, including high strength and ultra-high strength materials, reactive powder concrete, fiber-reinforced concrete, and externally bonded cementitious layers and other coatings. The papers were to be presented during two technical sessions scheduled for the ACI Spring 2020 Convention in Rosemont, Illinois, but the worldwide COVID-19 pandemic disrupted those plans.

The editors thank the authors for their outstanding efforts to showcase their most current research work with the concrete community, and for their assistance, cooperation, and valuable contributions throughout the entire publication process. The editors also thank the members of ACI Committee 370, the reviewers, and the ACI staff for their generous support and encouragement throughout the preparation of this volume.

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Iurie Curosu, Viktor Mechtcherine, Daniele Forni, Simone Hempel and Ezio Cadoni

Synopsis: Strain-hardening cement-based composites (SHCC) represent a special type of fiber reinforced concretes, whose post-elastic tensile behavior is characterized by the formation of multiple, fine cracks under increasing loading up to failure localization. The high inelastic deformability in the strain-hardening phase together with the high damage tolerance and energy dissipation capacity make SHCC promising for applications involving dynamic loading scenarios, such as earthquake, impact or blast.

However, the main constitutive phases of SHCC, i.e. matrix, fibers and interphase between them, are highly rate sensitive. Depending on the SHCC composition, the increase in loading rates can negatively alter the balanced micromechanical interactions, leading to a pronounced reduction in strain capacity. Thus, there is need for a detailed investigation of the strain rate sensitivity of SHCC at different levels of observation for enabling a targeted material design with respect to high loading rates.

The crack opening behavior is an essential material parameter for SHCC, since it defines to a large extent the tensile properties of the composite. In the paper at hand, the rate effects on the crack opening and fracture behavior of SHCC are analyzed based on quasi-static and impact tensile tests on notched specimens made of three different types of SHCC. Two SHCC consisted of a normal-strength cementitious matrix and were reinforced with polyvinyl-alcohol (PVA) and ultra-high molecular weight polyethylene (UHMWPE) fibers, respectively. The third type consisted of a high-strength cementitious matrix and UHMWPE fibers. The dynamic tests were performed in a split Hopkinson tension bar and enabled an accurate description of the crack opening behavior in terms of force-displacement relationships at displacement rates of up to 6 m/s (19.7 ft/s).

Keywords: SHCC, fiber reinforcement, strain-hardening, PVA, UHMWPE, impact, split Hopkinson tension bar, fracture energy

Iurie Curosu is a Postdoctoral Researcher at the Institute of Construction Materials, Faculty of Civil Engineering at the Technische Universität Dresden, Germany. His research activity is closely related to the multidisciplinary Research Training Group GRK 2250 "Mineral-bonded composites for enhanced structural impact safety". His research interests encompass high-performance fiber reinforced cementitious composites, such as Strain-Hardening Cement-Based Composites (SHCC) and Textile Reinforced Concrete (TRC). In the context of severe dynamic loading scenarios and structural strengthening with thin, impact resistant overlays, he works on material analysis and design by means of multi-scale, experimental and numerical methods.

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INTRODUCTION

SHCC consist of fine-grained cementitious matrices and short, high-performance polymer fibers in volume fractions of up to 2% [1]. The micromechanics-based material design aims a balance between the cracking behavior of the cementitious matrix and crack bridging behavior of the fibers, in this way ensuring a pronounced tensile ductility through the successive formation of fine, densely spaced cracks under increasing tensile loading. The remarkably high strain capacity of SHCC in combination with their favorable fresh-state properties allows their efficient application not just as main material in structural elements but also as thin strengthening layers on existing structures [2-6], including those prone to severe dynamic actions [7-9].

However, under increasing loading rates, the disproportionate changes of the components' properties alter the micromechanical balance as achieved for the case of quasi-static loading [10]. This might yield negative effects on the composite tensile behavior [11-14]. For the formulation of reliable material design concepts with respect to increased loading rates, the rate effects at the level of constituents, of the collective crack bridging and of the resulting composite behavior must be investigated and quantified.

Several studies were reported on the effect of increasing loading rates on the tensile behavior of SHCC, most of them being conducted in the range of low and moderate loading rates [9,11,13]. With regard to impact tensile loading, few reports were published [12,15,16], among which only Curosu et al. [16] and Heravi et al. [17] offered a detailed quantitative characterization of the impact tensile behavior of various SHCC in form stress-strain curves.

The crack opening behavior and fracture energy of notched SHCC specimens were only investigated in [12,15] in Hopkinson bar spall experiments. Using the evaluation methodology proposed by Schuler et al. [18], the specific fracture energy was derived from the impulse transfer between the separated fragments of notched specimens. These investigations provided valuable insights into the effects of high loading rates on the tensile behavior of SHCC