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FIBRE HIGH-STRENGTH SELF-COMPACTING CONCRETE

Academic Session : 2022/2023 - 1

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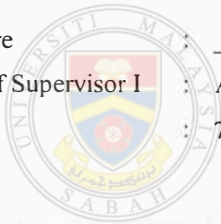
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HIGH- STRENGTH SELF-COMPACTING CONCRETE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Civil Engineering
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NOVEMBER 2022

DECLARATION

I declare that this thesis entitled "*Bond behaviour of deformed steel rebars in steel fibre high-strength self-compacting concrete*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

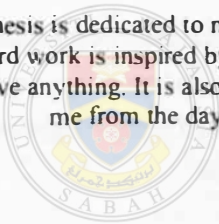
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DEDICATION

This thesis is dedicated to my late father, who passed away while I was studying. All this hard work is inspired by him who always taught me that through hard work I can achieve anything. It is also dedicated to my mother, who never stopped praying for me from the day I was born. I love you both with all my heart.



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ACKNOWLEDGEMENT

First and foremost, I would like to thank God for giving me the strength and grace I needed to complete this thesis. I am nothing without Him.

I would like to express my sincere gratitude to my supervisor Prof. Dr. Ahmad Baharuddin Abd. Rahman for trusting me to conduct the research work and for always supporting, guiding and sharing his wisdom with me. Thank you for believing in me. I am also thankful to my co-supervisors Prof. Ir. Dr. Azlan Adnan and Assoc. Prof. Dr. Roslli Noor Mohamed for their continuous support and guidance throughout my studies.

I am also indebted to Universiti Malaysia Sabah (UMS) for funding my Ph.D. studies and I am especially grateful to Assoc. Prof. Ts. Dr. Ismail Saad, the Dean of Faculty of Engineering, Universiti Malaysia Sabah, for his continuous support. Also, a special thank you to Prof. Ir. Dr. Abdul Karim Mirasa, the former Dean of Faculty of Engineering, Universiti Malaysia Sabah, for giving me the opportunity to pursue my Ph.D. studies.

My thanks and appreciation also goes to all the technicians of the Materials and Structure Laboratories (D04) especially to Ms. Mazlina Binti Ngah and Mr. Muhammad Anwarrasyid Bin Mohd Alwi for helping me a lot in the experimental work. Thank you to all of my postgraduate friends from D04 especially to Ir. Dr. Zuraida, Zanariah, Shariwati, Dianah, Ayun, Azie, Nadirah, Nur Fatin, Fazlin, Nur Suhadah, Annur, Azura and Chiew Shing Mei for assisting me in the experimental work and for their generosity in sharing knowledge and information. Their views and tips were useful indeed.

I also want to thank my family members especially my beloved father, the late Fabian Majain Lajini and to my mother Jovita Moinin, siblings (Genevive, Jonas, Regina, Sr. Marie Carmen and Emily), sister and brothers-in-law, nieces and nephews and also my uncles and aunties for consistently praying for me to complete my studies successfully and also for being so understanding.

I am forever thankful to the most faithful of friends in my life, Melissa Nicholas and Melissa Audrey Francis for their unending prayers, support, and encouragement. Thank you for always being there for me throughout all of my ups and downs in my study life.

Finally, I would like to thank all of my friends in GIFT UTM especially Joanne and Jason for helping me in my research work. Also, my deepest appreciation to all of my friends in Eramaju Synergy Sdn. Bhd., especially to Ir. Dr. Tom Ngui and Ir. Roland Ng for their continuous support and encouragement throughout my studies.

ABSTRACT

Studies on the bond behaviour of deformed steel rebars in conventional concrete have been widely covered. However, the studies on the bond behaviour between deformed steel rebars and high-strength self-compacting concrete (HSSCC), particularly with the addition of steel fibres, are still very limited. Hence, in this research, an in-depth study was conducted to investigate the effects of steel fibres on the bond behaviour of deformed steel rebars embedded in steel fibre high-strength self-compacting concrete (SFHSSCC). Experimental works were carried out in two phases. Phase 1 involved the design of concrete mixes and the testing of fresh and mechanical properties of the normal vibrated concrete (NVC), HSSCC and SFHSSCC. The steel fibres used in SFHSSCC were the hooked-end type with 35 mm length and an aspect ratio of 63.6. The research works in Phase 2 involved the direct pullout testing conducted according to the RILEM RC6 Part 2 standard. A total of 72 pullout specimens with a dimension of 200 mm x 200 mm x 200 mm were prepared and tested at 30 ± 2 days. A few of SFHSSCC specimens were tested at the 6 months of concrete age. The pullout specimens comprised high yield deformed steel rebars of 12, 16, and 20 mm diameters. The pullout specimens were subjected to increasing axial pullout load. The test results in Phase 1 showed the proposed design mix of self-compacting concrete managed to achieve high compressive strength of $60\text{-}80 \text{ N/mm}^2$. As compared to HSSCC, the concrete compressive strength of SFHSSCC had increased slightly, but the splitting tensile strength had increased tremendously. The results showed that SFHSSCC with 1.0% of steel fibre volume fraction was the best mix that satisfy the self-compacting and harden concrete requirements and therefore was selected for further study in Phase 2. The test results of Phase 2 showed that the effect of steel fibres in increasing bond strength between rebar and the high-strength self-compacting concrete is seen to be insignificant as the results of bond strength of rebars in HSSCC and SFHSSCC concrete showed small differences only. However, the addition of steel fibres in SFHSSCC had improved the concrete ductility very significantly. At the age of 6 months, the confinement energy of the SFHSSCC improved substantially by about 80% as compared to the confinement energy at 30 ± 2 days. Based on the stress-strain behaviour in concrete, it was observed that the SFHSSCC was able to expand significantly under large stresses with controllable strains which justifies that the presence of steel fibres had contributed to improved confinement effects to the extent that the SFHSSCC had the ability to provide high confinement energy and good ductility. Subsequently, based on the pullout test results, two new bond strength equations are proposed to predict the bond strengths of deformed steel rebars embedded in HSSCC and SFHSSCC. Finally, it can be concluded that the presence of steel fibres in SFHSSCC could overcome the brittle failure in high strength self-compacting concrete and significantly improves the concrete ductility, which delay the loss of bond between rebars and concrete.

ABSTRAK

Kajian mengenai kelakuan ikatan tetulang keluli berbunga dalam konkrit konvensional telah dilaksanakan dengan meluas. Bagaimanapun, kajian mengenai sifat ikatan antara tetulang keluli berbunga dan konkrit kekuatan tinggi terpadat sendiri (HSSCC), terutamanya dengan penambahan gentian keluli, masih sangat terhad. Oleh itu, dalam penyelidikan ini, kajian lebih mendalam telah dilakukan untuk menyelidik kesan gentian keluli terhadap sifat ikatan tetulang keluli berbunga yang tertanam dalam konkrit kekuatan tinggi terpadat sendiri dengan gentian keluli (SFHSSCC). Kerja-kerja ujikaji dijalankan dalam dua fasa. Fasa 1 melibatkan reka bentuk campuran konkrit dan ujian sifat konkrit segar dan mekanikal bagi konkrit bergetar normal (NVC), HSSCC dan SFHSSCC. Gentian keluli yang digunakan dalam SFHSSCC adalah jenis hujung bercangkuk dengan panjang 35 mm dan nisbah aspek 63.6. Kerja penyelidikan Fasa 2 melibatkan ujian tarik-keluar langsung yang dijalankan mengikut piawaian RILEM RC6 Bahagian 2. Sejumlah 72 spesimen tarik-keluar dengan dimensi 200 mm x 200 mm x 200 mm telah disediakan dan diuji pada 30 ± 2 hari. Beberapa spesimen SFHSSCC juga telah diuji pada umur konkrit 6 bulan. Spesimen tarik-keluar menggunakan tetulang keluli berbunga alahan tinggi berdiameter 12, 16, dan 20 mm. Spesimen tarik-keluar dikenakan beban tegangan paksi yang meningkat. Keputusan ujian Fasa 1 menunjukkan reka bentuk campuran konkrit terpadat sendiri yang dicadangkan dapat mencapai kekuatan mampatan tinggi di antara 60-80 N/mm². Berbanding dengan HSSCC, kekuatan mampatan konkrit SFHSSCC meningkat sedikit, tetapi kekuatan tegangan pecah meningkat dengan sangat tinggi. Keputusan menunjukkan SFHSSCC dengan 1.0% pecahan isipadu gentian keluli adalah campuran terbaik yang memenuhi keperluan konkrit terpadat sendiri dan konkrit keras dan telah dipilih untuk kajian lanjut di Fasa 2. Keputusan ujian Fasa 2 menunjukkan kesan gentian keluli dalam peningkatan kekuatan ikatan di antara tetulang keluli dengan konkrit kekuatan tinggi terpadat sendiri dilihat tidak ketara kerana hasil kekuatan ikatan tetulang keluli dalam konkrit HSSCC dan SFHSSCC menunjukkan perbezaan yang sedikit. Bagaimanapun, penambahan gentian keluli dalam SFHSSCC telah meningkatkan kemuluran konkrit SFHSSCC dengan sangat ketara. Pada umur 6 bulan, tenaga pengurangan SFHSSCC meningkat dengan ketara sehingga 80% berbanding tenaga pengurangan pada 30 ± 2 hari. Berdasarkan penyelidikan sifat tegasan-terikan dalam konkrit, telah diperhatikan bahawa SFHSSCC dapat mengembang dengan ketara di bawah tegasan yang besar dengan terikan terkawal yang membuktikan bahawa kehadiran gentian keluli telah menyumbang kepada kesan pengurangan yang lebih baik sehingga SFHSSCC mempunyai keupayaan untuk memberikan tenaga pengurangan yang tinggi dan kelakuan mulur yang baik. Seterusnya, berdasarkan keputusan ujian tarik keluar, dua persamaan kekuatan ikatan baharu telah dicadangkan untuk meramalkan kekuatan ikatan tetulang keluli berbunga yang tertanam dalam HSSCC dan SFHSSCC. Akhirnya, dapat disimpulkan bahawa kehadiran gentian keluli dalam SFHSSCC dapat mengatasi kegagalan rapuh dalam konkrit kekuatan tinggi terpadat sendiri serta meningkatkan kemuluran konkrit dengan ketara, yang melambatkan kegagalan ikatan di antara tetulang keluli dan konkrit.

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