

REINFORCED AND POROUS MATERIALS

FOR STRUCTURAL APPLICATIONS

Engineers and scientists are continuously trying to develop engineering materials with better physical and mechanical properties. In order to achieve this, a good amount of knowledge particularly in materials science and mechanics of materials is required. Nevertheless, it is also well understood that it is less likely to develop a material with improvement in every aspect of the properties. Therefore, it is essential to study the properties that are targeted to be improved based on the intended application. In view of this, this book highlights some studies on the reinforced and porous materials for specific engineering applications. The aim is to provide some information to the readers, such as engineers, researchers, academicians as well as graduate students to know the selection of design and testing parameters in developing advanced engineering materials.

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EDITED BY
WONG KING JYE
MUHAMMAD FARUQ FOONG MOHAMAD FAIZ FOONG



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Preface

It is always a challenge for materials used in advanced engineering applications to exhibit excellent physical and mechanical properties. Therefore, research and development on materials with improved properties are always extensive and continuous. This relies on good fundamental knowledge particularly in mechanics of materials and materials science. In view of this, this edited book intends to collect some of the recent findings on the reinforced and porous materials used for specific engineering applications.

This book consists of ten chapters. It begins with some highlights on the design of composite laminates through fibre orientation and stacking sequence selections. Then, the studies on natural fibres in terms of flexural behaviour and acoustic performance are presented. Next, the potential of metal fibre as reinforcement for low velocity impact performance is reported. It is followed by the characterisation of particulates reinforcement on AA6061 alloy composites. After that, a brief review on conductive polypyrrole/polyurethane composites is summarised. Subsequently, the fire-retardancy, thermal stability, foam morphology, and compressive properties of nanosilica particles reinforced polyurethane foam are determined. Finally, the potential use of porous architecture for bone scaffold application is highlighted.

The contribution by all authors in this book, titled *Reinforced and Porous Materials for Engineering Applications*, is specifically acknowledged.

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Muhammad Faruq Foong Mohamad Faiz Foong
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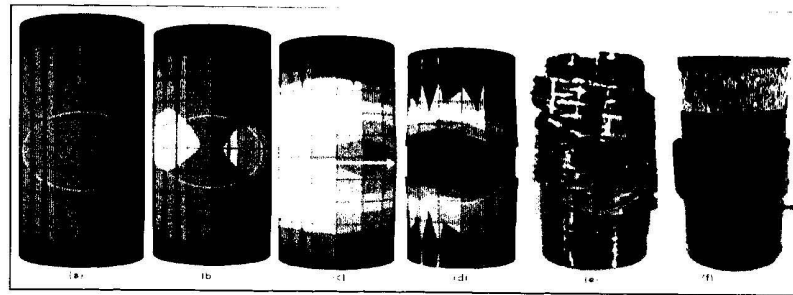


Figure 8.11 FRP confinement material failure (a) Load from TSPC core transferred to FRP confinement and increasing in FRP confinement material (b) FRP confinement material starts to soften (c) The lateral expansion occurs on FRP confinement (d) Failure occurs as sudden delamination (e) Sudden rupture and debonding failure mode on experimental GFRP confinement (f) Sudden delamination and debonding failure mode on experimental CFRP confinement

8.6 CONCLUSION

This study present numerical investigation on TSPC column with FRP material confinement under compression by FEM. The experimental and proposed FEM using ABAQUS commercial software package has shown similarity in strength enhancement with the application of GFRP and CFRP confinement on TSPC column through stress - strain curve produced. In addition to that, the failure observation from experimental and FEM simulation has also shown acceptable match with some deficiencies. The reason is that the exact value of compressive strength, yield strength and compressive modulus has shown some deviation between FEM and experimental. Although not precisely, the measured value of the parameters between FEM and experimental may be concluded as approximate match due to similar trend produced. FRP parameters is suggested to be improved to upgraded the FEM that has been developed.

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REFERENCES

- ABAQUS. (2014). *Analysis User's Manual, Version 6.14*. Dassault Systemes Simulia, Inc.
- Abed, F., Oucif, C., Awera, Y., Mhanna, W. H. H., & Alkhraish, A. (2020). FE modeling of concrete beams and columns reinforced with FRP composites. *Defence Technology*, 17(1), 1-14.
- ACI 440.2R-08. (2008). *Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures*. American Concrete Institute.
- ASTM C192 / C192M-19. (2019). *Standard Practice for Making and Curing Concrete Test Specimens*. Laboratory, ASTM International.
- ASTM C579-01. (2021). *Standard test methods for compressive strength of chemical-resistant mortars, grouts, monolithic surfacing and polymer concretes*. ASTM International.
- Bedi, R., Chandra, R., & Singh, S. P. (2014). Reviewing some properties of polymer concrete. *Indian Concrete Journal*. 88(8), 47-68.
- Berardi, V. P. (2021). Fracture failure modes in fiber-reinforced polymer systems used for strengthening existing structures. *Applied Science*, 11(14), 6344.
- Chellapandian, M., Prakash, S. S., & Rajagopal, A. (2017). Analytical and finite element studies on hybrid FRP strengthened RC column elements under axial and eccentric compression. *Composite Structures*. 184, 234-248.

- Faidzal, M. M. Y., Hassan, S. A., Omar, B., Zakaria, K., & Zaharuddin, M. F. A. (2018). Particle Size effect on optimal mixture ratio of tin slag polymer concrete under compression. *Journal of Built Environment, Technology and Engineering*, 5, ISSN 0128-1003.
- Ganesh, C., & Muthukannan, M. (2019). Finite Element Analysis over Geopolymer Concrete using ABAQUS. *International Journal of Engineering and Advanced Technology (IJEAT)*, 9(14), DOI:10.35940/ijeat.A1024.1291S419
- Goh, W. I., Mohamad, N., Abdullah, R., & A. A. A. Samad. (2014). Compression test and finite element analysis of foamed concrete cube. *Journal of Engineering and Technology*, 5(1).
- Hadhood, A., Mohamed, H., & Benmokrane, B. (2018). Flexural stiffness of GFRP- and CFRP-RC circular members under eccentric loads based on experimental and curvature analysis. *ACI Structural Journal*. DOI: 115.10.14359/51702235.
- Hashin, Z. (1980). Failure criteria for unidirectional fiber composites. *Journal of Applied Mechanics, Transactions ASME*, 47, 329-334.
- Hassan, S.A., Hanan, U.A., Yahya, M.Y., & Wahit, M.U. (2020). Behaviour of tin slag polymer concrete confined with carbon fibre reinforced epoxy. *Jurnal Penelitian dan Karya Ilmiah Lembaga Penelitian Universitas Trisakti*, 5(2), 0853-7720, ISSN (e): 2541-4275.
- James, F., & Shackelford. (2015). *Introduction to materials science for engineers 8th edition*. Pearson.
- Kim, H. J., Yi, N. H., Kim, S. B., Nam, J. W., Ha, J. H., & Kim, J. H. (2011). Debonding failure analysis of FRP-retrofitted concrete panel under blast loading. *Structural Engineering and Mechanics*, 38(4), 479-501.
- Kolloor, R., Saeid, S., Karimzadeh, A., Yidris, N., Petru, M., Ayatollahi, M., & Tamin, M. (2020) An energy-based concept for yielding of multidirectional FRP composite

- structures using a Mesoscale Lamina Damage Model. *Polymers*, 12, 1-18.
- Li, P., Sui, L., Xing, F., Huang, X., Zhou, Y., & Yun, Y. (2018). Effects of aggregate types on the stress-strain behavior of fiber reinforced polymer (FRP)-confined lightweight concrete. *Sensors*, 18(10), 3525.
- Liao, W. C., Chen, P. S., Hung, C. W., & Wagh, S. K. (2020). An Innovative Test Method for Tensile Strength of Concrete by Applying the Strut-and-Tie Methodology. *Materials*, 13(12), 2776.
- Manda, M. S., Rejab, M. R. M., Hassan, S.A., & Quanjin, M. (2022). A review on tin slag polymer concrete as green structural material for sustainable future. In Hassan R. *et al.*, (eds.), *Green Infrastructure*. Springer.
- Micelli, F., Cascardi, A., & Aiello, M. A. (2018, July 17-19). *A Study on FRP-confined concrete in presence of different preload levels* [Conference session]. 9th International Conference on Fibre-Reinforced Polymer (FRP) Composites in Civil Engineering.
- Micha, S., & Andrzej, W. (2015). Calibration of the CDP model parameters in Abaqus. *Advances in Structural Engineering and Mechanics (ASEM15)*, 1-11.
- Petrik, A & Ároch, R. (2019). *Usage of true stress-strain curve for FE simulation and the influencing parameters* [Conference session]. IOP Conference Series: Materials Science and Engineering.
- Polus, P., & Szumigala, M. (2019). *Laboratory Tests vs. FE Analysis of Concrete Cylinders Subjected to Compression* [Conference session]. AIP Conference Proceedings.
- Popovics, S. (1967). *Relations between various strengths of concrete*. In Proceedings of the 46th Annual Meeting of Portland Cement and Concrete, USA.
- Raza, A., Masood, B., & Hussain, I. (2020b). Finite element modelling and theoretical predictions of FRP-reinforced

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