A review on Use of Peridynamics in Crack Propagation

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Abstract

Crack propagation is an important parameter in design of components. Failure of components subjected to fatigue depends on initiation and propagation of crack. Numerous techniques have been used to model and study crack propagation. This paper reviews the use of Peridynamics for crack propagation.

Keywords

Peridynamics, Crack Propagation

Introduction

Most of the components in machines and automobiles are subjected to time dependant forces that result in fatigue failure. Fatigue results in failure of a component before yield stress is reached. Due to fatigue, cracks form in the component and propagate with time and results in failure of the component. Many times, crack is not formed on surface but within the material which makes it impossible to determine crack before it reaches surface. In such cases, failure occurs all of a sudden before any warning or sign of crack is observed. This makes study of crack initiation and propagation very important.

Different techniques have been used to study the process of crack propagation. Earlier fracture mechanics was used to analytically model cracks and study its propagation. With advancements, now computers are used to numerically solve the problems using finite element method and its variants. In fracture mechanics, crack initiation and development have been the prime matter of discussion. A wide variety of techniques for nucleation and propagation of crack have been developed by varying the failure criteria and theory of continuum mechanics.

This paper discusses the use of Peridynamics for studying crack propagation.

Literature Review

Researchers have studies crack initiation and propagation by using following approaches: extended finite element method (XFEM), peridynamics, numerical manifold method and phase field modeling. Extended finite element method is advancement of finite element method where enrichment function is used to introduce discontinuity (cracks) in the model. Numerical manifold method[1] combines the continuum based finite element method with discontinuous deformation analysis (DDA) to determine the crack propagation path. Phase field modeling [2] gives solution to the problems involving phase boundary evolutions that happens as a result of phase transformations

Peridynamics is a nonlocal method[3] in which material points interact not only with their nearest neighbours but also with points nearby, inside a horizon.

Table 1: Literature Review

Year	Author	Application Area	Summary
2008 [4]	Michael L. Parks, Richard B. Lehoucq, Steven J. Plimpton Stewart A. Silling	Peridynamics within molecular dynamics	Authors have shown that the inter-particle forces that result from discretizing PD have a functional form analogous to interatomic potentials commonly used in molecular dynamics. Impact of rigid sphere on a brittle disc was studied and results agreed with EMU.
2008 [5]	S.A. Silling, R.B. Lehoucq	Classical elasticity theory	Authors found that if the motion, constitutive model, and any non-homogeneities are sufficiently smooth, then the peridynamic stress tensor converges in this limit to a Piola-Kirchhoff stress tensor that is a function only of the local deformation gradient tensor, as in the classical theory.
2009 [6]	Florin Bobaru, Stewart A. Silling, Mijia Yabg, Ebrahim Askari, Leonardo F. Alves, Jifeng Xu	Adaptive refinement in 1D peridynamics	Authors have presented adaptive refinement algorithms for peridynamics. It was found that using functions with jump discontinuity at edge of the horizon reduced the quadratic rate of convergence. The method was found beneficial in the applications involving local stress concentrations.
2014 [7]	Daniele Dipasquale, Mirco Zaccariotto, Ugo Galvanetto	Adaptive grid refinement	Authors presented a method to generate nodes in the refined zone for efficient computation. Dynamic crack propagation in brittle material was studied and a framework was demonstrated for carrying out concurrent multiscale modeling.
2015 [8], [9]	Oterkus, Selda	Multiphysics problems	Author have used peridynamics to study elastic and plastic deformation by considering a plate under loading and unloading. Peridynamics was also used to solve problems using thermal and moisture diffusion. Then coupled problem of plate deformation with moisture diffusion was solved and results were found in close agreement with the experimental results.

2015 [10]	Lai, Xin , Bo Ren, Houfu Fan, Shaofan Li, C.T.Wu, Richard A. Regueiro, Lisheng Liu	Fragmentation due to impulse load	Authors have developed non linear peridynamic approach to model and simulate dynamic fragmentation when components made of brittle materials are subjected to impact load. Proposed method was implemented to different problems and found consistent with analytical and FEM results.
2016 [11]	Huilong Ren, Xiaoying Zhuang, Yongchang Cai, Timon Rabczuk	Dual horizon peridynamics	Authors have introduced the concept of dual horizon peridynamics that consider unbalanced interactions between the particles with different horizon sizes. The method has been found effective for both 2d and 3d problems.
2016 [12]	Dennj De Meo, Cagan Diyaroglu, Ning Zhu, Erkan Oterkus, M. Amir Siddiq	Stress corrosion cracking	Authors have presented a technique for the modelling of adsorbed- hydrogen stress-corrosion cracking (SCC), based on the adsorption-induced decohesion mechanism.

Conclusion

Peridynamics have been used by several researchers to study crack propagation. Different aspects of peridynamics have been explored to efficiently model and solve the problem. Peridynamics has evolved as a powerful numerical particle method that has many advantages in predicting complex fracture and fragmentation processes of solids.

References

[1] S. Yang, M. Cao, X. Ren, G. Ma, J. Zhang, and H. Wang, "3D crack propagation by the numerical manifold method," *Comput. Struct.*, vol. 194, pp. 116–129, 2018, doi: 10.1016/j.compstruc.2017.09.008.

[2] R. Spatschek, E. Brener, and A. Karma, "Phase field modeling of crack propagation," *Philos. Mag.*, vol. 91, no. 1, pp. 75–95, 2011, doi: 10.1080/14786431003773015.

[3] S. A. Silling, "Reformulation of elasticity theory for discontinuities and long range forces," *J. Mech. Phys. Solids*, vol. 48, no. 1, pp. 175–209, 2000, doi: https://doi.org/10.1016/S0022-5096(99)00029-0.

[4] M. L. Parks, R. B. Lehoucq, S. J. Plimpton, and S. A. Silling, "Implementing peridynamics within a molecular dynamics code," *Comput. Phys. Commun.*, vol. 179, no. 11, pp. 777–783, 2008, doi: 10.1016/j.cpc.2008.06.011.

[5] S. A. Silling and R. B. Lehoucq, "Convergence of peridynamics to classical elasticity theory," *J. Elast.*, vol. 93, no. 1, pp. 13–37, 2008, doi: 10.1007/s10659-008-9163-3.

[6] F. Bobaru, M. Yang, L. F. Alves, S. A. Silling, E. Askari, and J. Xu, "Convergence, adaptive refinement, and

scaling in 1D peridynamics," *Int. J. Numer. Methods Eng.*, vol. 77, no. 6, pp. 852–877, 2009, doi: 10.1002/nme.2439.

[7] D. Dipasquale, M. Zaccariotto, and U. Galvanetto, "Crack propagation with adaptive grid refinement in 2D peridynamics," *Int. J. Fract.*, vol. 190, no. 1–2, pp. 1–22, 2014, doi: 10.1007/s10704-014-9970-4.

[8] E. Madenci and E. Oterkus, *Peridynamic Theory and Its Applications to Diffusion Equation*, vol. c, no. 2. .

[9] S. Oterkus, "Peridynamics for the solution of multiphysics problems," *Dissertation*, p. 288, 2015, [Online]. Available: http://hdl.handle.net/10150/555945.

[10] L. L. Lai, Xin , BoRen, Houfu Fan, Shaofan Li, C.T.Wu, Richard A. Regueiro, "Peridynamics simulations of geomaterial fragmentation by impulse loads," *Int. J. Numer. Anal. Methods Geomech.*, vol. 30, no. 13, pp. 1303–1336, 2015, doi: 10.1002/nag.

[11] H. Ren, X. Zhuang, Y. Cai, and T. Rabczuk, "Dual-horizon peridynamics," *Int. J. Numer. Methods Eng.*, vol. 108, no. 12, pp. 1451–1476, 2016, doi: 10.1002/nme.5257.

[12] D. De Meo, C. Diyaroglu, N. Zhu, E. Oterkus, and M. A. Siddiq, "Modelling of stress-corrosion cracking by using peridynamics," *Int. J. Hydrogen Energy*, vol. 41, no. 15, pp. 6593–6609, 2016, doi: 10.1016/j.ijhydene.2016.02.154.