XLI CILAMCE
XLI Ibero-Latin American Congress on Computational Methods in Engineering
16-19 November, 2020 FOZ DO IGUAÇU PARANÁ - BRAZIL

Peridynamics as Predictive Maintenance Tool for Crack Monitoring

Heitor Nunes Rosa[1], Davi Moraes Monelli[1], Márcio Antonio Bazani[1]

[1]*Departament of Mechanical Engineering, Unesp*
Avenue Brasil 56, 15385-000, Ilha Solteira/São Paulo, Brazil
h.rosa@unesp.br, davi.monelli@unesp.br, marcio.bazani@unesp.br

Abstract. The purpose of this work is to demonstrate the initiation and propagation of a crack in a plate of an A-36 Structural Steel with a pre-existing notch through simulation using a peridynamic model. In the analise it was used a mesh established through the discretization of 250,000 material points distributed between coordinates x and y of dimensions: 0.05 meters of length and width and 3x10−4 meters of thickness. A notch of 0.012 meters was added to the left side of the plate breaking the peridynamic interactions between material points of the site. A force of 10,000 Newtons was applied over the entire lower. In the explicit integration, pairwise forces were calculated for all points using peridynamic interactions of the neighboring points in addition to the influence of loading. Determining the acceleration of a point, velocity and displacement were calculated. Time step used was approximately Δt = 13,37ns to stability and convergence criterion. The software used to resolve was FORTRAN and demonstrated results VisIt. It was concluded that for the specific component of a pre-notched plate of A-36 Structural Steel, common material for mechanical constructions, the results demonstrated that the nucleation phenomena were well represented by the models and peridynamic simulations. The discovery of the crack propagation direction and its velocity are also extremely important to know the degree of plate commitment, since in the final state of integration the crack length reached almost 37% of the plate length.

Keywords:first keyword, second keyword, third keyword (up to 5 keywords).

1 Introduction

Any mechanical system or equipment is subject to deterioration. This deterioration leads to the appearance of defects that can disrupt the continuity and quality of the service (production). An unplanned break translates into a sudden stop, often leading to heavy losses and loss of production time and maybe production accidents [4]. As [3] says, for the productivity of an industry, consisting of a huge diversity of machines and equipment, to have positive results, it is necessary that all of them be kept in the best working conditions. Thus, all of these equipment must undergo repairs, scheduled inspections, programmed and adequate preventive routines, replacement of parts, oil changes, lubrication, cleaning, painting and correction of defects. All these actions constitute what is called maintenance. The most used is the division into the types: preventive, corrective and predictive maintenance. Therefore, a recent tool is being used and it stands out in the field of Predictive Maintenance. Peridynamics (PD) is able to inform the development of crack from early stages until the complete destruction of mechanical components [2]. Peridynamic characteristics allow the initiation and development of fractures modeled by arbitrating the paths without the need of special simulation, like finite element method (FEM) or extended finite element method (XFEM) [6]. The PD showed to be a promising method for the exact area and, considering the exposed factors, the present work had as objective to demonstrate the initiation and propagation of a crack in a plate of A-36 Structural Steel with a pre-existing notch through simulation using a peridynamic model.

2 Methodology and Results

The equation PD which describes motion is a nonlinear integral-differential equation in time and space, and consequently, there are several difficulties for an analytical resolution. Therefore, for the exposed model the resolution was performed using the explicit numerical integration method using FORTRAN software due to the high computational cost.

$$\rho \frac{d^2}{dt^2} u(x,t) = \int_{Hx} f(\eta, \xi) dV_{x'} + b(x,t) \tag{1}$$

In Equation (1), ρ represents material density and d2 u(x,t)/dt2 acceleration in function of time and space. The integration takes place over Hx, defined as ”horizon”, where material points are connected within the horizon via elastic bonds. f(η,ξ) is the pairwise force in the peridynamic bond and represents the interaction between the material points in function of η and ξ , relative displacement and position respectively. Vx′ is the volume of each material point and finally b(x,t) represents the body force. Peridynamics as a maintenance tool for cracks detection A mesh was established through the discretization of 250,000 material points distributed between coordinates x and y in A-36 steel plate of dimensions: 0.05 meters of length and width and 3x10−4 meters of thickness. The dimensions of length and width were based on work of Ha and Bobaru (2010), and the thickness for future practical works. A notch of 0.012 meters was added to the left side of the plate breaking the peridynamic interactions between material points of the site. A force of 10,000 Newtons was applied over the entire lower. In the explicit integration, pairwise forces were calculated for all points using peridynamic interactions of the neighboring points in addition to the influence of loading. Determining the acceleration of a point, velocity and displacement were calculated. Time step used was approximately Δt = 13,37ns to stability and convergence criterion. Software used to display results was VisIt [7], since FORTRAN is not capable. A representative schematic of the component can be seen in Fig. 1:

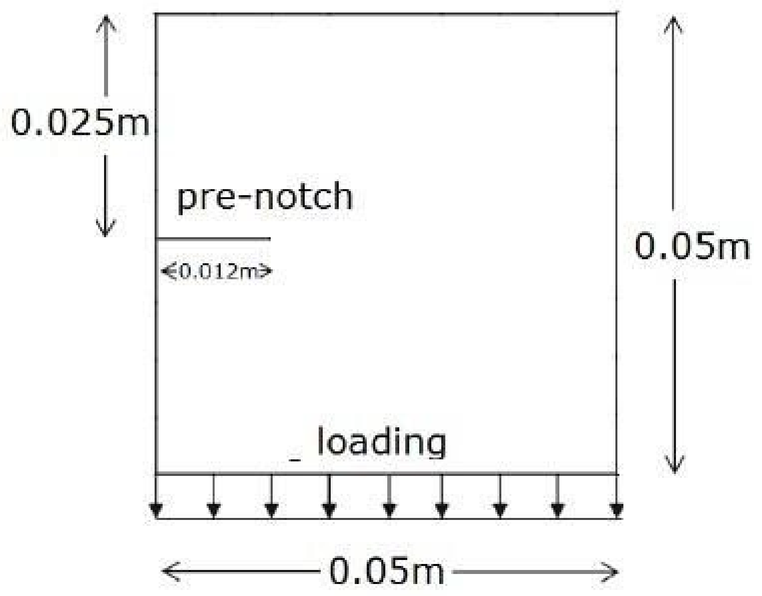

Figure 1 – Representation of the A-36 Structural Steel plate in scale with a pre-notch

The length of the crack was measured from the final location of the notch for all of the integration steps cited in Fig. 2. The colored caption represents the percentage of damage inflicted on peridynamic bonds. It is perceived that the interior of the discontinuities is more fragile than the boundary and frontier regions. The work [6] under different parameters, such as a notch in the center of the plate with speed applied as a boundary condition, instead of applied loads, also observed that the PD theory captures with a more significant success in the initiation of cracks. Just as in this present work, it is possible to visualize birth and its development.

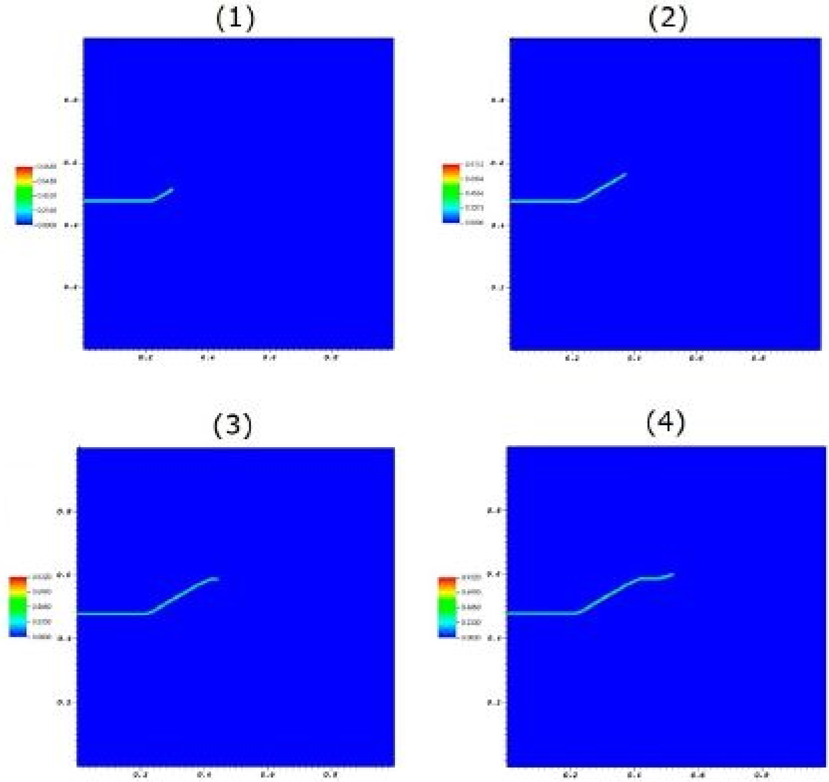

Figure 2 – Simulation of crack propagation in a structural steel with loading of 10 kN at the end of (1) 750 steps of time, (2) 1,000 steps of time, (3) 1,250 steps of time, and (4) 1,500 steps of time.

2.1 Results

It was important to note that the direction of propagation of the discontinuity is opposite to the side of the loading application on the plate, being this fact of extreme importance for mechanical components with non-symmetrical request.

In work [1] and [7] it is observed that for large values of symmetrical loads the crack propagation will divide into a river-delta crack pattern.

The growth of the crack as a function of time is shown in Figure 3, and the crack growth speed can be evaluated as 939 m/s. The developmental profile was approximately linear, as observed by Madenci and Ortekus (2014), although the speed found by the authors was higher and defined by 1,650 m/s. The value was also considerably below 1580 m/s measured in experiments by [1], although the material used by the authors was soda-lime glass.

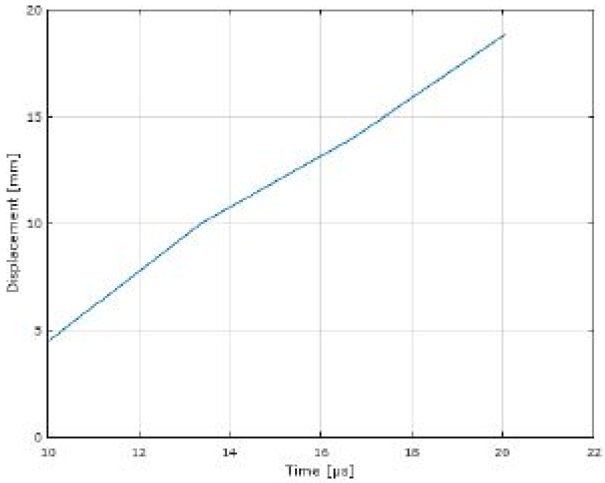

Figure 3 – Crack growth as function of time.

This work is in its initial phase and we are learning how to program the Peridynamics tool. The great difficulty is found in the location of material points, mainly in the interaction of internal forces with such points. It will study an example that is part of the book: “Peridynamics and Its Applications” [6], which we will intend to do the same procedure as the previous example, where the circular hole is considered a pre-existing crack, as shown in Figure 4. Also, its horizontal edges are subjected to a very fast rate of stretch (velocity) in order to observe how the rate of loading affects the evolution of dynamic crack growth. The plate properties and geometry are the same as before except for the thickness.

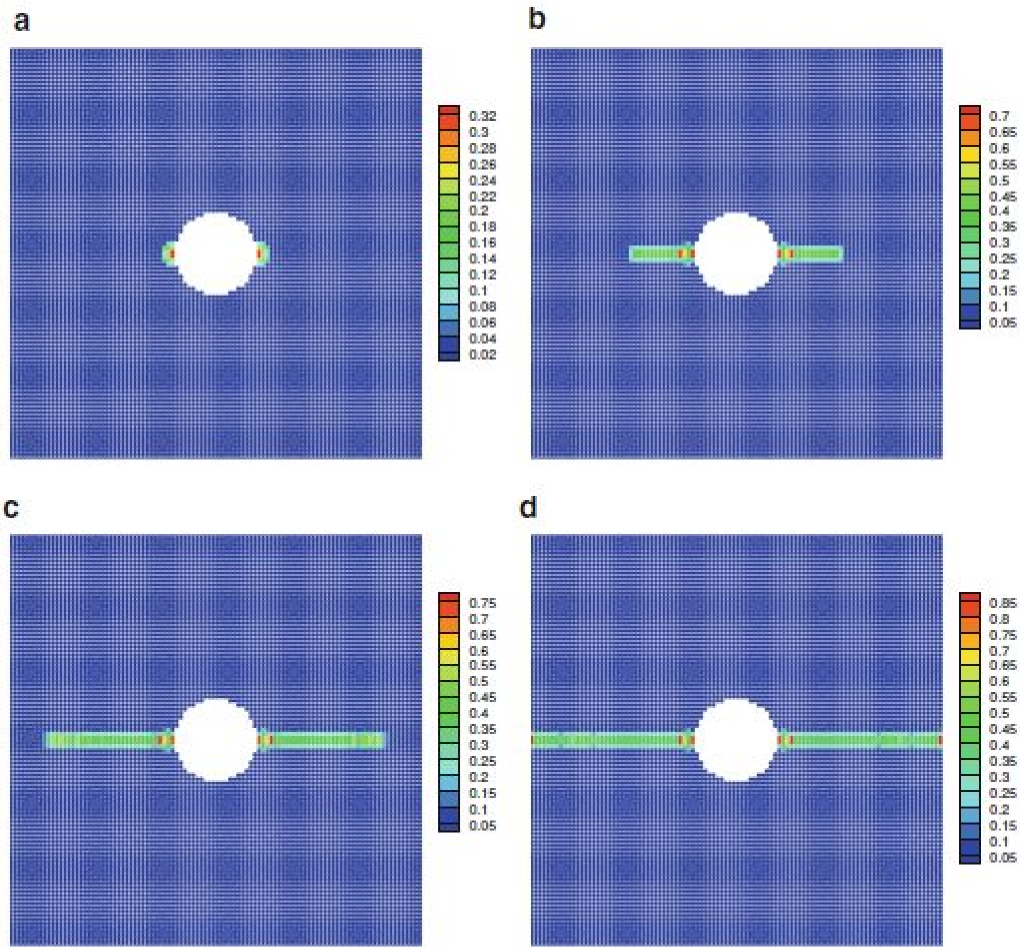

Figure 4 – Damage plots for the plate with a circular cutout at the end of: a) 650 time steps, b) 700 time steps, c) 800 time steps and (d) 1000 time steps [6]

3 Conclusions

In this work, theoretical studies were presented using peridynamic theory to represent the initiation, development and speed of cracks. It was concluded that for the specific component of a pre-notched plate of A-36 Structural Steel, common material for mechanical constructions, the results demonstrated that the nucleation phenomena were well represented by the model and peridynamic simulation based on the Equation of Peridynamic. The simulation showed the crack direction and its velocity without having to insert any special crack propagation criteria. In the final state of integration, the crack length reached almost 37% of the plate length.

Acknowledgements. Special thanks to Gustavo Mestriner, pioneer of this work in our group.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship)of the authors, or has the permission of the owners to be included here.

References

[1] F. P. Bowden, J. H. Brunton, J. E. Field and A. D. Heyes, ”Controlled fracture of brittle solids and interruption of electrical current”, Nature, Vol.216, pp. 38-42, 1967.
[2] A. C. Goncalves, S. Ekwaro-Osire and F. M. Alemayehu, ”Probabilistic Prognostics and Health Management of Energy Systems”, Springer, Germany, Vol.1, pp. 189-194, 2017.
[3]A. C. Goncalves. and J.B. Campos-Silva, ”Predictive maintenance of a reducer with contaminated oil under an excentrical load through vibration and oil analysis”, Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol.33, pp. 1-7, 2011.
[4]A. C. Goncalves and L. R.Padovese, ”Vibration and oil analysis for monitoring problems related to water contamination in rolling bearing”, Proceedings of the 1st International Brazilian Conference on Tribology TriboBR 2010 and ITS - IFTo MM 2010 - 2nd International Tribology Symposium of IFToMM, Rio de Janeiro, 2010.
[5]Y. D. Ha and F. Bobaru, ”Studies of dynamic crack propagation and crack branching with peridynamics”, International Journal of Fracture, Vol., pp. 229-244, 2010.
[6] Madenci, E. and E. Oterkus, ”Peridynamic Theory and Its Applications”, Springer, New York, Vol.1, pp. 175-178, 2014.
[7] M. Ramulu and A. S. Kobayashi, ”Mechanics of crack curving and branching dynamic fracture analysis”, International Journal of Fracture, Vol.27, pp. 187-201, 1985.
[8] Visit https://wci.llnl.gov/simulation/computer-codes/visit.