Numerical simulation of high and weak discontinuity using the Mesh-free approach in the 3D material domain

Akash Gupta[1]

[1]School of Mechanical Engineering, Lovely Professional University, Phagwara-144411, Punjab-India

Akash.19350@lpu.co.in

Abstract:

The present chapter aims at providing a generalized model for studying crack in layered materials. This study has been performed using EFGM. The results and plots obtained are compared and validated with standard FEM. EFGM significantly reduces the computational time and engineering effort compared to FEM. J-Integral is used to calculate SIFs and a novel Jump Function approach is used to detect the change in material properties in coatings. The crack is provided at centre of substrate and its variations with respect to SIFs are plotted. The Weak discontinuity that is material interface has been successfully detected along with strong discontinuity that is crack using intrinsic enrichment in one domain.

Keywords: Element free Galerkin Method, Fracture Analysis, Bi-Layered Materials, Finite Element Analysis, Horizontal Crack, Inclined Crack.

1. Introduction:

Materials has been become the part of human life since the very existence and also there has been various developments took place in metal industry. The need of same metal being used for a variety of applications lead to the improvement of the mechanical and thermal properties which includes strength, resistance to corrosion and high temperatures etc.,[1]. Then the researchers show some attention to develop layered materials which possess the potentiality of being used for various applications mostly in mechanical and aerospace industries[2]. Layered materials consists a substrate coating of any other material on the substrate material, for example Aluminium coating on steel, in which aluminium provides the corrosion resistance in the top of substrate steel material[3]. Similarly, there are varieties of substrate available in the market which can be applied as a coating on different materials using various processes[4].

Though, the layered materials provide required mechanical and thermal properties for their application areas, also there are some challenges facing by these materials[5]. Crack is one of the major problems which happen often on any material surface may leads to failure[6]. Almost all the mechanical structures contain micro and macro level cracks and propagates or leads to form new cracks in real working conditions[7][8]. So, analysis of cracks is therefore very important.

Standard and extended finite element methods can be employed to study the cracks in homogeneous materials and to predict the crack growth and path[9], similarly, the same procedure can be followed to study the effect of crack in bi-materials[10]. So, this study deals the effect of the presence of crack in the substrate material with different lengths under mechanical loading using Element Free Galerkin Method (EFGM). The results and plots are compared with the standard Finite Element Method (FEM).

2. Numerical Implementation:

The numerical implementation of the present work has been done using MATLAB. The problem contains a rectangular plate with dimensions height 3 units and width 2 units. Width of the plate divided in to three parts as 1 unit for substrate material and 0.5 units on each side for coating material**.** The problem domain is discretized by 25 nodes along x-direction and 37 nodes along y-direction making total of 925 nodes. The crack is located at the centre of the substrate metal and the investigation is carried out for various lengths and inclinations. The SIFs measured in this study represents the stress field for the right tip of the crack. Two types of metal configurations are considered for this study with steel and aluminium as follows:

i. Aluminium/Steel/Aluminium configuration:
   In this configuration, steel is considered as substrate metal with aluminium coating on both sides and the effect of crack for various lengths (a=0.3, 0.4, 0.5, 0.6 and 0.7)
ii. Steel/Aluminium/Steel configuration:
   This configuration contains aluminium as substrate metal and steel coating of 0.5 unit width on either side is provided and studied the effect of crack for various as mentioned above.

The lower edge of the plate is fixed and restricted to move in all directions and a load of 5000N is applied on the top edge which promotes mode I loading condition. Materials used and their mechanical properties are shown in the following Table.1.

Table 1: Materials and their mechanical properties

S.No	Material	Young's Modulus	Poison's Ratio
1	Steel	210 Gpa	0.3
2	Aluminium	70 Gpa	0.33

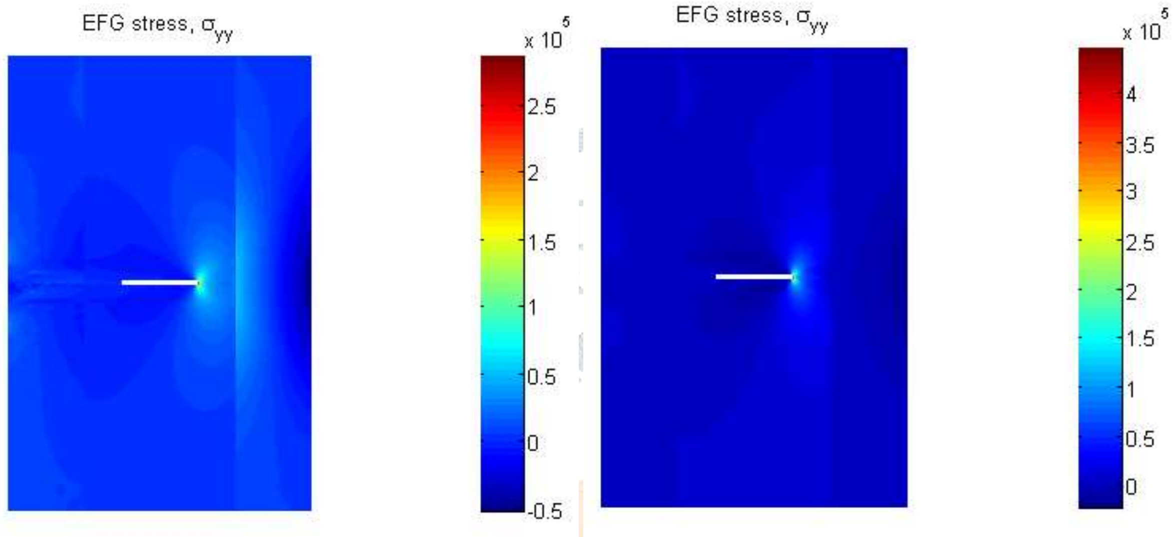
3. Results and Discussion:

3.1 Analysis of horizontal centre crack:

In this section, the horizontal centre crack ($\theta=0^0$) which is shown as a white line at the centre in figure.1 studied by varying length using EFGM for both the configurations and obtained SIF's are compared with standard FEM results. The crack length is varied from 0.3 units to 0.7 units stress fields are calculated for right tip of the crack. It is noticed that, Mode-I SIF (K_I) keeps on increasing along with length for both configurations as shown in figure.2(a) which gives the directly proportionality of SIF with length. The SIF

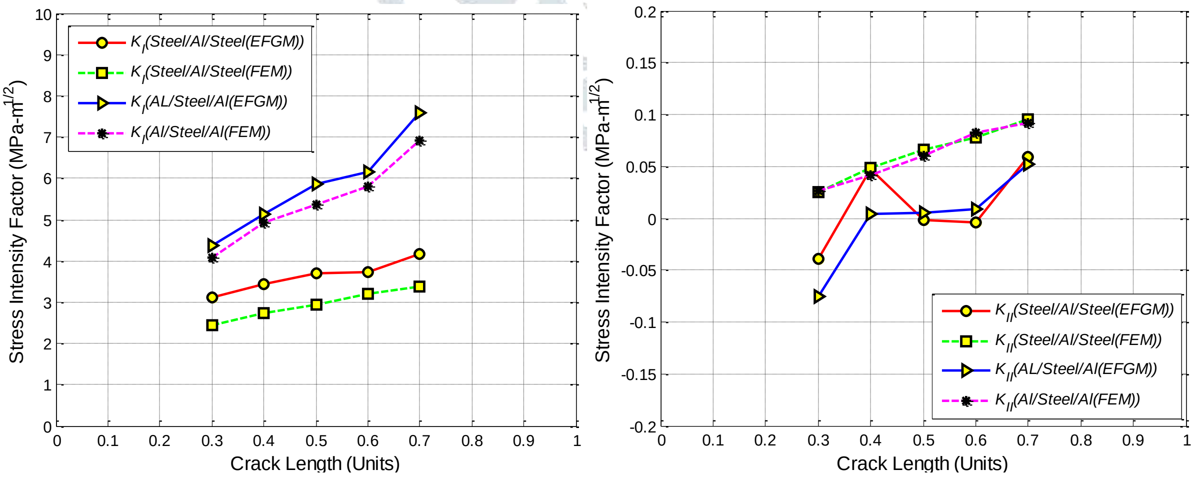
(K_I) values for configuration Al/Steel/Al are more compared to Steel/Al/Steel for both methods (EFGM&FEM).

For the same loading conditions, stress intensities of Al/Steel/Al are observed to be high than Steel/Al/Steel configuration. This may be due to the higher values of mechanical properties for steel material. Similarly, SIF values for mode-II (K_{II}) is also studied for both the configurations and shown in figure. 2(b). But, the results are observed to be very low as the crack is completely subjected to mode-I loading condition so SIFs doesn't show any effect to the substrate material for both the configurations.



(a) (b)

Figure.1: Contour plot of y-stress (σ_{yy}) for horizontal crack (a) Steel/Al/Steel configuration (b) Al/Steel/Al configuration



(a) (b)

Figure.2: Plots of SIFs for various lengths under mechanical load for Steel/Al/Steel and Al/Steel/Al configurations (a) Mode-I (b) Mode-II

4. Conclusion:

The work produces some enticing results in understanding the fracture behaviour of a simple multi-layered material. The work gives results more suited to real life conditions. Major findings from the work are as follows:

- SIFs for Al/Steel/Al configuration are observed to be higher than Steel/Al/Steel configuration for both the conditions.
- As length of the crack increases, SIFs values of mode-I are also noticed to increase for both the configurations dominated by the configuration having steel as substrate material whereas SIFs of mode-II are fluctuating with the length

Though material steel possess more strength and other mechanical properties than aluminium, results are coming out in the favour for configuration with aluminium as substrate material with low SIFs in all the above mentioned cases. A further work can be done to study the effect of crack in coating material as well as substrate.

References:

[1] G. Bhardwaj, I. V. Singh, and B. K. Mishra, "Stochastic fatigue crack growth simulation of interfacial crack in bi-layered FGMs using XIGA," *Comput. Methods Appl. Mech. Eng.*, vol. 284, pp. 186–229, 2015.

[2] L. Bouhala *et al.*, "An XFEM crack-tip enrichment for a crack terminating at a bi-material interface," *Eng. Fract. Mech.*, vol. 102, pp. 51–64, Apr. 2013.

[3] C. Dai-Heng, "A crack normal to and terminating at a bimaterial interface," *Eng. Fract. Mech.*, vol. 49, no. 4, pp. 517–532, 1994.

[4] A. Chamat *et al.*, "Crack behaviour in zinc coating and at the interface zinc-hot galvanised TRIP steel 800," *Eng. Fract. Mech.*, vol. 114, pp. 12–25, 2013.

[5] A. Romeo and R. Ballarini, "A Crack Very Close to a Bimaterial Interface," *J. Appl. Mech.*, vol. 62, no. September, p. 614, 1995.

[6] S. H. Chen, T. C. Wang, and S. Kao-Walter, "A crack perpendicular to the bimaterial interface in finite solid," *Int. J. Solids Struct.*, vol. 40, no. 11, pp. 2731–2755, 2003.

[7] V. Sura and S. Mahadevan, "Modeling of vertical split rim cracking in railroad wheels," *Eng. Fail. Anal.*, vol. 18, no. 4, pp. 1171–1183, 2011.

[8] B. N. Rao and S. Rahman, "Mesh-free analysis of cracks in isotropic functionally graded materials," *Eng. Fract. Mech.*, vol. 70, no. 1, pp. 1–27, 2003.

[9] K. Nasri, M. Abbadi, M. Zenasni, and Z. Azari, "Numerical and experimental study of crack behaviour at the zinc/TRIP steel 800 interface," *Comput. Mater. Sci.*, vol. 82, pp. 172–177, 2014.

[10] K. Nasri, M. Abbadi, M. Zenasni, M. Ghammouri, and Z. Azari, "Double crack growth analysis in the presence of a bi-material interface using XFEM and FEM modelling," *Eng. Fract. Mech.*, vol. 132, pp. 189–199, 2014.

[11] M. Pant, I. V. Singh, and B. K. Mishra, “Evaluation of mixed mode stress intensity factors for interface cracks using EFGM,” *Appl. Math. Model.*, vol. 35, no. 7, pp. 3443–3459, 2011.

[12] K. Sharma, V. Bhasin, I. V. Singh, B. K. Mishra, and R. K. Singh, “Simulation of Bi-metallic Interfacial Cracks Using Element Free Galerkin Method,” *Procedia Eng.*, vol. 86, pp. 685–692, 2014.

[13] R. C. Batra, M. Porfiri, and D. Spinello, “Treatment of material discontinuity in two meshless local Petrov-Galerkin (MLPG) formulations of axisymmetric transient heat conduction,” *Int. J. Numer. Methods Eng.*, vol. 61, no. 14, pp. 2461–2479, 2004.

[14] J. R. Rice, “A Path Independent Integral and the Approximate Analysis of Strain Concentration by Notches and Cracks,” *J. Appl. Mech.*, vol. 35, no. 2, p. 379, 1968.