INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.4 Issue 5,

May 2016

Pgs: 115-121

Mesh Generation method of One Dimensional Heterogeneous Object Using Genetic Algorithm

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Abstract

The objective of the paper is to describe the concept of using genetic algorithm procedure in optimization the mesh size of heterogeneous objects. Mesh size optimization is understood in the sense of heterogeneity in the object. The attention is focused on the applicability of genetic algorithms in conjunction with the finite element method. The mathematical model develop from finite element methodology and taken node as a variable and derived rule for objective function and get a node position in the object as well as mesh size of object and final mesh is generated. Various numerical examples illustrate to discuss the mesh strategy and compared with other mesh methods for heterogeneous method.

Keywords: Heterogeneous object, Mesh generation, Genetic algorithm

1. Introduction

Any engineering system is said to be different and reliable if and only if, it satisfy all the functional requirements for which it is to be designed. Functionally of a system or any part of it best when it possesses desired properties at required location. In many cases, we need to have different mechanical properties at different places in same structure as functional requirement. Homogeneous material/object fails to deliver such characteristics. So, new material called heterogeneous material (HM) or functionally Graded material (FGM) which gradual variation of material and material properties have come into play to replace homogeneous materials in the prevailing conditions.

Similar to design methods, the computational simulation are very vital instruments of analysis in many engineering disciplines because of their potential to reduce of costly physical experiments. One of the fundamental considerations in computer simulation is how to treat continuous and complex domain in small elements to form a simple sub domains having regular geometry, this is the most important step in numerical simulations called mesh generation. Researchers are work on area of heterogeneous meshing with mesh generation algorithms Chiv W.K. et.al 2011. Introduced a material Quad-tree for mesh generation of heterogeneous object, Yongjie Zhang et al 2010. describes an automatic and efficient approach to construct mesh of composite domain made up of Heterogeneous material, J.C.M. Teo et al 2007. meshed model generated from VHD (visible human dataset) of spine using grid based approach, Chawla A. et al 2006. Presents a new technique is develop to make FE model of bones from MRI/CT scan data, Nicole A. et al 2009. develop multi-block technique for mesh generation that ease the effort and reduce time require to current FE meshed model, Y. Su , Present an algorithm to generate an all hexahedral mesh of a multi domain solid using hybrid grid based approach. Yoshitaka Wada et. al 2002, Described an automated mesh generation method intelligent local approach (ILA). John M. Sullivan 1997, A conceptually straightforward and computational efficient system is presented that automatically generates three-dimensional finite element meshes for completely arbitrary, multi-material domains. And many more researchers work on FE analysis of Heterogeneous object Uday V Pise et al 2009. Objective of this study is to simulate static loading of bio-objects like human femur with B-Spline based modeling and its 3D finite element analysis with graded element. T.B. Pfeiler et al 2007. The work was to develop and test a semi-automated finite element mesh generation method using computed tomography (CT) image data of a canine radius. Pinghai Yang et al 2007. A new approach for intuitively modeling of multi material objects termed heterogeneous lofting. In analysis module, a novel graded B-Spline finite element solution procedure. In most of the papers author gives more emphasis on mesh generation for modeling of heterogeneous object, discretized heterogeneous object according to different material region that's why the element shape is considered at the interior and exterior of the domain and material region but the element size will not considered. In present work author introduced an algorithm for mesh generation for heterogeneous object using Genetic algorithm (GA) and illustrate various numerical examples to compared with other mesh size examples.

In present work Genetic algorithm (GA) is introduced, it is well known as spatial search algorithm based on the mechanism of natural selection and natural evolution.GA is based on Darwin principle of natural selection it means by which beneficial variation in the population tends to be preserved while unfavorable variation tends to be lost.

Author derived objective function for a heterogeneous object one dimensional problem from finite element methodology, and considers nodes as a variables that after optimization procedure completed mesh size will generated for heterogeneous object problem

2. Mesh Generation Method Using Genetic Algorithm

Author introduce Genetic algorithm for meshing the heterogeneous object. As per as literature only few paper available in which genetic algorithm is used for mesh generation which also limit to homogeneous material. The process of mesh generation method using genetic algorithm for heterogeneous object is shown in figure 1. The method has processes, which are described as mesh generation, in addition to a simple GA. The additional processes are designed to produce objective function equation and controlled mesh size.

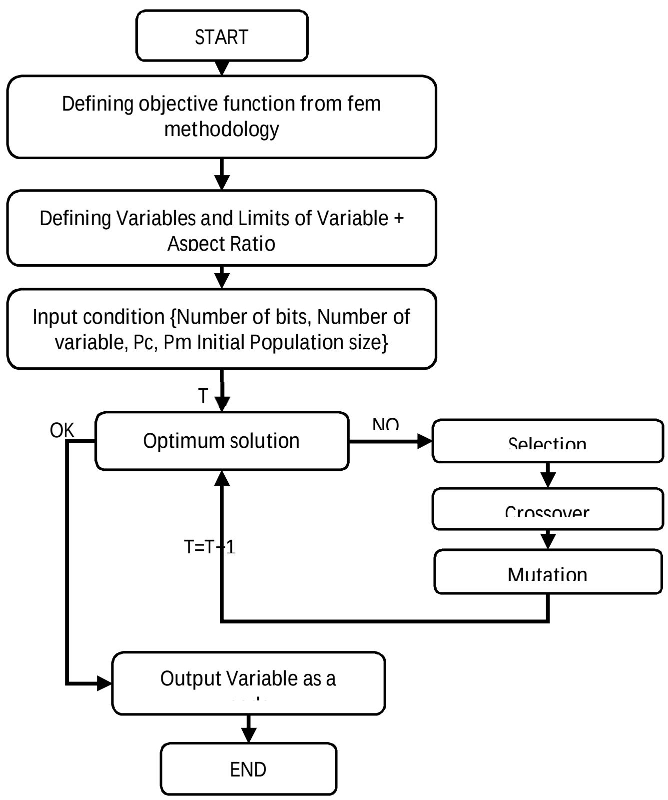

Figure 1: Flow chart of mesh generation method using genetic algorithm

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2.1. Mathematical Model

Let us start the simplest problem of one dimensional heterogeneous object of length L with material property varies between E_0at first node and E_n at end node to the power of (n= 2, 3, 1/2, 1/3) as shown in figure 2.

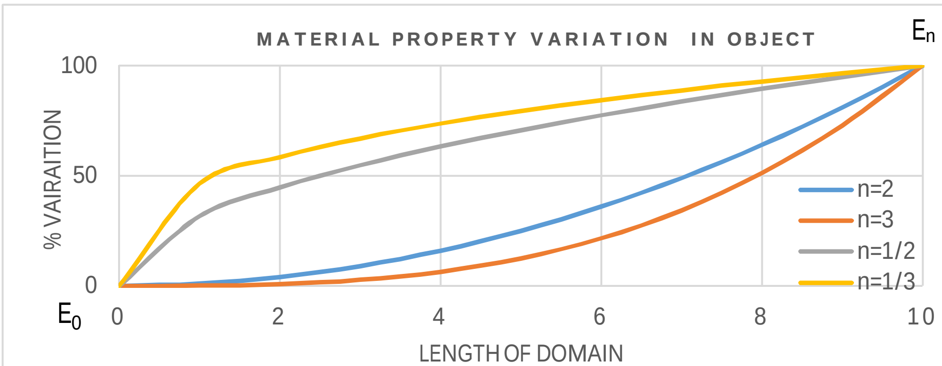


Figure 2: Material variation in one dimensional heterogeneous object

Initial and final node dimension is known and in between node is unknown called as x or variable. Le length of element is which is a depended function of x is shown in figure 3. Ae is an area and E_1, E_2, E_3, E_4 is the material property of nodes which is also depended function of x

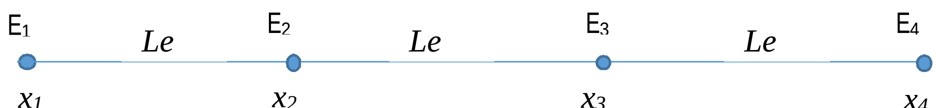


Figure 3: One dimensional object and nodes

$\text{Le} = x_{(i+1)} - x_i$ Le is length of element and function of x

$\text{Ee} = E_{(i)} + (E_{(i+1)} - E_{(i)})\frac{x}{L}$ Ee is young modulus of element and function of x

$\text{Ke} = \frac{\text{Ae}*\text{Ke}}{\text{Le}}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$ Ke Stiffness matrix of element and function of x

$\{U\}\{K\} = \{F\}$ Finite element equation for a problem from direct approach

Where K is Global stiffness matrix, F is force matrix and U is displacement matrix.

The finite element equation consist value in terms of variable and while solving for the desired field variable the equation is derived is the objective function for genetic algorithm and x (nodes) is a variables.

Optimal solution depends on the exact solution of the defined problem or nature of result predicted (maximum or minimum).

2.2. Variable and Variable limits

In FE analysis their n number of nodes and author taken nodes as a variable in mesh generation method using genetic algorithm and previous section objective function is defined with n number of variable or Objective function having multivariable problem and the variable had bounded between local minimum and local maximum between nodes. In figure 2 the end points nodes will be known and internal nodes is unknown, that unknown node is variable in genetic algorithm objective function. Variable range is shown

$$x_i \le x_{(i+1)} \le x_{(i+2)}$$

While in optimization, sometimes the distance between the variable is very close, the distance between them is called element, if the size of element is small it will create artificial stiffness matrix or failed during analysis and output result comes abrupt therefore while making some criteria or aspect ratio the problem will solve.

3. FE analysis of heterogeneous object

Simple bar of length 10cm, Area is $1cm^2$,One end is fixed and tensile load of 400KN is applied at another end, Material variation is $E(x) = E_{(1)} + (E_{(2)} - E_{(1)})\left(\frac{x}{L}\right)^n$, & E_1=10Gpa and E_2=1000Gpa and n is order of Material Variation shown in figure 4

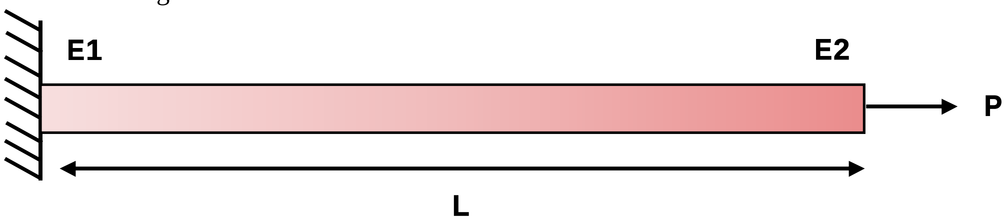
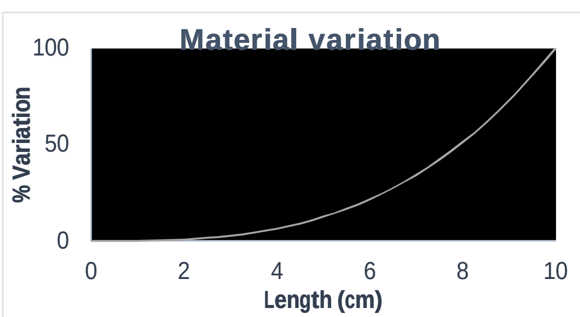


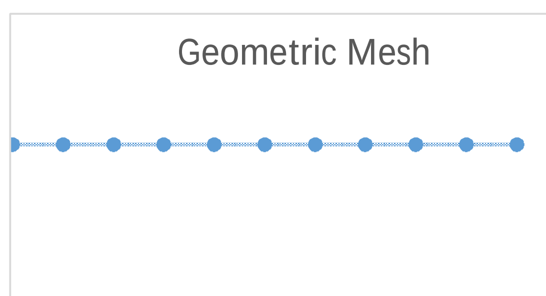
Figure 4: One heterogeneous object, loading and boundary condition

3.1. Mesh Generation of Object

Mesh generation method is process of breaking up a physical domain in to smaller sub domain (element), for the comparison of result of field variables in different mesh size author uses three types of mesh generation methods:
Geometrical mesh: In geometrical mesh material property wasn't considered i.e. domain is divide in equal size element as shown in figure no. 5(b)
Material mesh: In material mesh material property was considered i.e. in one dimensional domain certain range of material property example 0-10%, 10%-20%, 20%-30% etc. in between areas is considered as element (unequal size element) as shown in figure no. 5(c)



(a)



(b)

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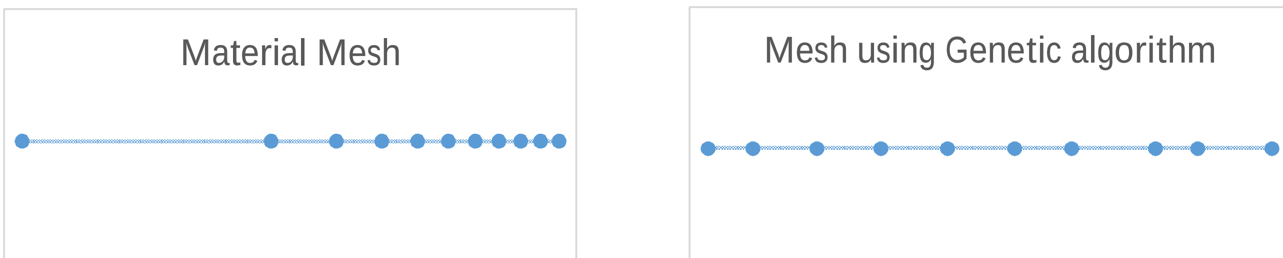


(c) (d)

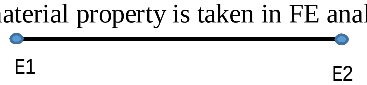
Figure 5: (a) Material variation in domain, (b) Geometric mesh, (c) material mesh (d) mesh generation using genetic algorithm

Mesh generation using Genetic algorithm: mesh generation considering the material property variation and size of element depend on objective function results

3.2. Element Material Property

In homogeneous object material property of every element in object is constant but in case of heterogeneous object material property of every element in object is change. Author use average element and graded element for solving the heterogeneous object

Average element: generally average of material property is taken in FE analysis software's. Average of material



property of two node is taken as element material property $E = (E1 + E2)/2$

Graded element: The graded element approach (Kim, 2002; Santare, 2002; Uday V. Pise, 2009) is used to improve the performance of the analysis. Elements which possess a spatially varying material property field in between two nodes $E = E1 + (E2 - E1)(\frac{x}{L})$

4. Numerical Studies

In this section, finite element simulation is done on one dimensional heterogeneous object with defined mesh generation strategy and assigns material property in element using average and graded element approach on proposed boundary condition and loading condition in a heterogeneous object.

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In Figure 6, the displacement obtained in one dimensional object with material variation (n=2, 3) due to FE analysis and compared with defined meshing strategy. It is observed that mesh generation using genetic algorithm with graded element is give better convergence as compared to geometric mesh with graded and average element and material mesh with graded element

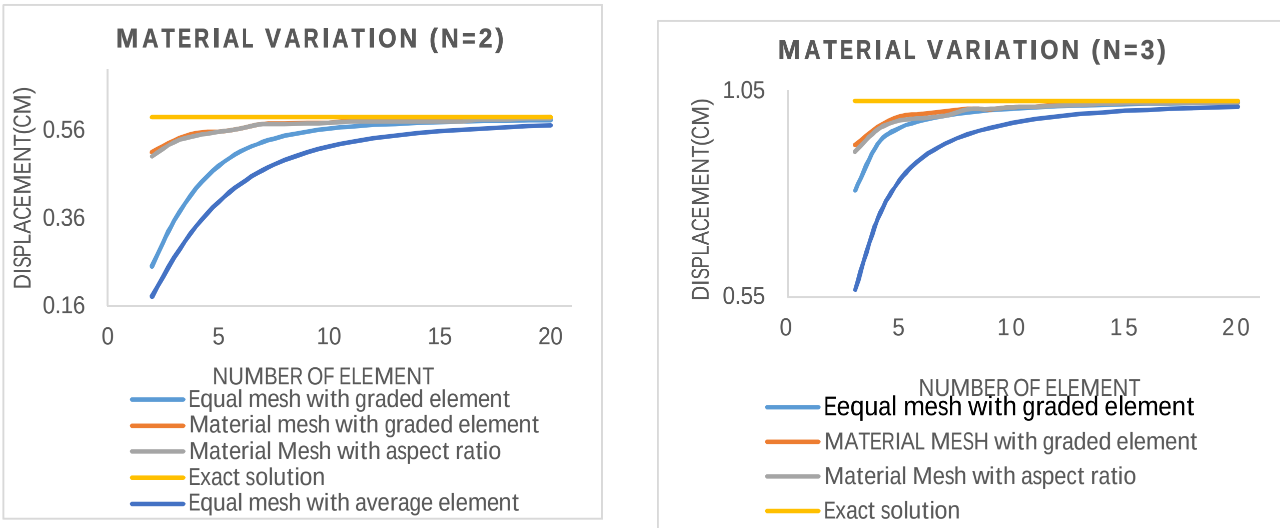

Figure 6: convergence results of heterogeneous object using different mesh schemes for (n=2, n=3) material power variations

In figure 7, the displacement obtained in one object in material variation (n=1/2, 1/3) due to FE analysis and compared with defined meshing strategy. It is observed that geometric mesh with average element approaching towards maximum value to minimum value of displacement but again the better convergence result comes in case of mesh generation using genetic algorithm as compared all other strategy.

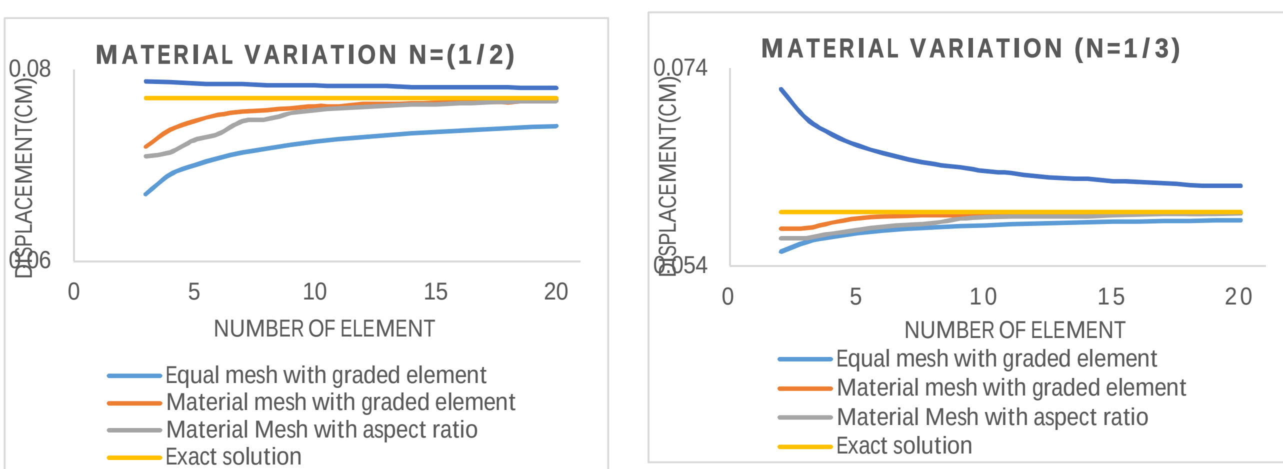

Figure 7: convergence results of heterogeneous object using different mesh schemes for (n=1/2, 1/3) material variations

5. Discussion

The goal of this study was to introduce genetic algorithm in mesh generation in heterogeneous object with graded element for FE analysis. Generally the accuracy prediction of the mechanical behavior of heterogeneous object in FE analysis depends on the mesh size and element material property. In genetic algorithm mesh generation method better results come in less number of elements and quality of element is in controlled automatically.

The FE result obtained for one dimensional heterogeneous object for any kind of material variation in the object in mesh generated by using genetic algorithm show good result as compare to other methods.

The mesh generation using genetic algorithm methodology with graded element presented in this paper has been numerically tested in variously material variation conditions and found to have good displacement prediction. It is also capable to obtain a good element so that artificial stiffness will not occur. The work in the direct is continued in two & three dimensional.

6. Conclusion

A new integrated method is described for reliable simulation of the mechanical response of heterogeneous object based on mesh generation using genetic algorithm for accurate element size of the object for FE analysis. Hence, it can be concluded that the detail FE model, can simulate all load configuration and all kind heterogeneous object. The result are consistent and in good agreement in displacement with the simulated studies. This technique will further implement on two and three dimensional object and for regular and irregular geometry and material property.

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