Second IITH Solid Mechanics Symposium

Book of Abstracts

Solid Mechanics Group

Indian Institute of Technology Hyderabad

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Schedule for the IITH Solid Mechanics Symposium

Venue: Auditorium, Academic Block A

Monday, 19th June

Time start	Time end		Speaker	Title of talk
8:30 AM	9:00 AM	Welcome, Registration, Tea + Coffee		
9:00 AM	9:10 AM		**Prashant Saxena**	Welcome address
Chair : Basant Lal Sharma				
9:10 AM	10:10 AM	Talk 1	**Namrata Gundiah**	Mechanics of fiber reinforced materials
10:10 AM	11:10 AM	Talk 2	**A.Narayan Reddy**	Introduction to Inverse Problems in Elasticity
11:10 AM	11:30 AM	Coffee Break		
Chair : Dhiraj Mahajan				
11:30 AM	12:30 PM	Talk 3	**Narayan Sundaram**	Flow instabilities in Large-Strain Plasticity in Metals Processing
12:30 PM	1:50 PM	Lunch (Upper Dining Hall)		
Chair : Namrata Gundiah				
2:00 PM	3:00 PM	Talk 4	**Guruprasad PJ**	Discrete Dislocation Dynamics: Challenges and Way Forward
3:00 PM	4:00 PM	Talk 5	**Basant Lal Sharma**	Some reflections on the discrete aspects of solid mechanics
4:00 PM	5:00 PM	Talk 6	**Syed N. Khaderi**	Mechanical properties of idealised inverse opal lattice
Closing of Day 1 and Group Photograph				

Tuesday, 20th June

Time start	Time end		Speaker	Title of talk
8:50 AM	9:00 AM	Quick tea + coffee		
Chair : Syed N Khaderi				
9:00 AM	10:00 AM	Talk 7	**Naresh Varma Datla**	Role of adhesion energy on the peeling behaviour of heterogeneous thin films
10:00 AM	11:00 AM	Talk 8	**Ratna Kumar A VVSD**	Pebble bed thermo-mechanics in breeder units of fusion reactors: heat transfer and packing studies
11:00 AM	12:00 PM	Talk 9	**Dhiraj Mahajan**	Towards Crystal Plasticity based Modeling of Hydrogen Metal Interaction
12:00 PM	2:20 PM	Poster Session and Lunch (Upper Dining Hall)		
Chair: A. Narayan Reddy				
2:30 PM	3:30 PM	Talk 10	**Anil Agarwal**	Structures in Fire: Towards performance based design
3:30 PM	4:30 PM	Talk 11	**Srikant S. Padhee**	Orthogonalization of Energy Functional: A New Way to Understand In-homogeneous Structures
4:30 PM	4:40 PM	Closing of Symposium		

Abstracts of speakers

Abstracts of posters

Structures in Fire: Towards performance based design

Anil Agarwal
Department of Civil Engineering, IIT Hyderabad

Abstract:

Most of the internationally recognized design guides for structural fire safety have a very prescriptive approach for the provision of structural fire protection. There are many examples of fire accidents that prove that the fire protection guidelines do not provide a consistent level of fire safety to structures. Some of the main reasons for this limitation of the codes are as follows. (1) The approach adopted by the codes addresses the safety of individual components rather than the structural system. (2) In addition to the reduction in stiffness and strength of the material, creep effects change the material response very significantly at elevated temperatures. (3) The typical static analysis tools employed for structural simulations are not adequate.

It has been observed in various fire accidents that some commonsense measures such as structural redundancy, alternate load paths, and some types of ductile detailing can delay or prevent a catastrophic collapse in fire conditions.

A number of case studies are conducted on buildings designed per existing design codes and their susceptibility to failure is assessed by carrying out detailed simulations for fire effects. It has been observed that (i) rigid connections in steel frame buildings help reduce the positive bending moment demand on the beam in fire conditions. This leads to the greater fire resistance of the floor system in comparison to beams connected with shear-only connections and (ii) that the use of fire protection material in floor system can be reduced by providing additional reinforcement in the floor system. Also, it was observed that columns that are exposed to fire from two or three sides are likely to have greater fire resistance than the columns that are exposed to fire from all four sides.

Some reflections on the discrete aspects of solid mechanics

Basant Lal Sharma
Department of Mechanical Engineering, IIT Kanpur

Abstract:

Traditionally solid mechanics is considered as a subject involving the continuum hypothesis at its core. The discrete aspects of solid mechanics pertaining to the physical structure, i.e. atoms, molecules, grains, etc., or to the numerical approach designed to solve the continuous problems, i.e. finite elements, finite difference grid, etc. have, however, maintained a close relation to the subject. The former are well known in the modeling schemes of crystalline materials, while the latter are encoded inside almost all universally applied tools of simulation softwares. Due to long and diverse historical reasons, the ingredients that have influenced the growth and richness of continuum mechanics have also found analogues in the discrete framework; some of these have remained quite crucial within the continuum model (despite the fundamentally different mathematical structures) due to the second source of discreteness, i.e. numerical algorithms. This talk will share some known, and a few, obscure results in the discrete vs continuum models in the subject of solid mechanics. The context of waves in solids will be used to provide illustrations. Some recent findings concerning the phenomenon involving the wave propagation in lattices, as well as the diffraction and scattering of such waves by edges, will be also discussed. The talk emphasizes the role of mathematics in handling discrete formulations at par with the well-established continuum.

References:

1. Sharma BL, "Glimpse of discrete mechanics", Directions IITK, May 2014, 76--86 (http://www.iitk.ac.in/directions/Directions_2014_01/article6.pdf) (preprint: http://home.iitk.ac.in/~bls/Homepage/directions1.pdf)

2. Sharma BL, "Near-tip field for diffraction on square lattice by crack", SIAM Journal on Applied Mathematics, 75(4), 1915-1940 Aug 2015 (http://epubs.siam.org/doi/ref/10.1137/15M1010646) (preprint: http://home.iitk.ac.in/~bls/Homepage/siamdiffracsq2.pdf) DOI 10.1137/15M1010646

3. Sharma BL, "Continuum limit of the discrete Sommerfeld problems on square lattice", Sadhana, Apr 2017 (http://link.springer.com/article/10.1007/s12046-017-0636-6) (preprint: http://home.iitk.ac.in/~bls/Homepage/sadhanacontinuum.pdf) DOI 10.1007/s12046-017-0636-6

Discrete Dislocation Dynamics: Challenges and Way Forward

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Abstract:

Discrete dislocation dynamics (DDD) framework provides a useful tool to address issues related to mechanical behavior of materials at a length scale intermediate between atomistic and continuum. The need for understanding the origins of heterogeneous plasticity and pattern formation in crystals led to the development of DDD. In DDD, appropriate equations of motion (viscous drag) are integrated to obtain dynamical evolution of a system of dislocations. Over the last decade, this framework has been successfully used to investigate scale effects (both structural and material), crack tip plasticity and the effects of voids on the overall inelastic deformation of the materials. Currently, it would be fair to accept that the fundamentals of DDD have been established. There are, however, challenges. These are two fold: (a) enhancing computational efficiency and (b) extending DDD to address new intriguing problems. Recent works in field have taken a forward step to meet the computational demands of the framework by the development of algorithms based on fast multipole method and parallel computing frameworks. Extending these computationally efficient techniques for the simulation of large polycrystals, however, is still elusive. Intriguing problems like grain boundary - dislocation interactions, modeling twins, coupled creep-fatigue modeling, irradiation effect, are still outstanding challenges which the DDD community is yet to successful tackle. In this talk, a broad outline of the current state of the art and possible future research directions in the field will be highlighted.

Mechanics of fiber reinforced materials

Namrata Gundiah
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Abstract:

Living tissues are complex, composite, anisotropic, and heterogeneous structures comprised of constituents that exhibit nonlinear and viscoelastic material properties. Tissues have a remarkable ability to alter their size, shape and material properties in response to mechanical stimuli such as during growth or in disease. The study of biomechanics is hence both fascinating and challenging and aims to apply methods in physics and engineering to quantify processes governing cellular and tissue properties. During the course of my talk, I will discuss the biomechanics of a rubber protein, elastin, isolated from vertebrate arteries. I will also focus on recent investigations in my lab to experimentally characterize the material properties of fiber reinforced elastomers in transversely isotropic layouts within a continuum mechanical framework. Through such studies, I hope to highlight the need for interdisciplinary research to address complex problems at the interface of biology and engineering.

Flow instabilities in Large-Strain Plasticity in Metals Processing

Narayan Sundaram
Department of Civil Engineering, Indian Institute of Science, Bangalore.

Abstract:

The importance of accurate simulation and modeling of metal processing operations (deformation processing and machining) can hardly be overstated. These simulations are among the most challenging in computational plasticity due to the fact that they involve some or all of the following: Large strains, high strain rates, thermoplastic effects, two-way coupling between the microstructure and mechanical response, ductile failure, and flow localization phenomena (e.g. shear banding).

This presentation is a report on a simple but effective model to include the effects of microstructure-induced spatial inhomogeneity on plastic flow and residual surface conditions in the simulation of deformation processing and metal cutting operations. The model is tested in a Lagangian FE simulation of sliding at various rake (and incidence) angles.

In particular, the model reproduces interesting unsteady plastic flow phenomena that have been observed by experimentalists at the 100-2000 micron scale. The proposed approach holds promise for application to a wider range of processes.

Role of adhesion energy on the peeling behaviour of heterogeneous thin films

Naresh Varma
Department of Mechanical Engineering, IIT Delhi

Abstract:

The peeling behavior of a heterogeneous thin film bonded to a rigid substrate is investigated using both experiments and finite element modeling. Specifically enhancement in peel force was studied for heterogeneous thin films with periodic stiff and compliant portions along the length. Peel tests with homogeneous thin films (uniform film thickness) showed that the maximum peel force can be observed before the onset of steady state peeling process. Moreover, this maximum peel force is a function of the bending stiffness of the film and adhesion energy at the film-substrate interface. For the heterogeneous thin films, maximum peel force can be observed either before the onset of steady state or when the peel front traverses from compliant to stiff portion of the film. Further insight into the enhancement in peel force was achieved with a developed three-dimensional finite element model based on cohesive zone technique. The maximum force depends on the level of heterogeneity, in addition to adhesion energy and bending stiffness as observed with homogeneous films. The improvement in peel force was found to be prevalent at relatively low adhesion energy. This study may be helpful for the better design of homogeneous and heterogeneous thin film-substrate systems having improved bonding strength.

Pebble bed thermo-mechanics in breeder units of fusion reactors: heat transfer and packing studies

Ratna Kumar Annabattula
Department of Mechanical Engineering, IIT Madras

Abstract:

Generation of power through nuclear fusion has been considered one of the most attractive means for clean and abundant energy. Currently, efforts are underway to demonstrate the viability of fusion power through fusion reaction of Deuterium and Tritium (D-T) both are isotopes of hydrogen. While Deuterium is abundant in the form ocean waters, tritium is scarce and its half-life time is less than 12 years. Further, there is no economic means of producing tritium on industrial scale at present. Hence, for a successful D-T fusion concept, tritium should be bred within the reactor. It is known that Tritium can be produced by bombarding a high energy neutron with Lithium atom. Tritium breeder materials are in the form of pebbles made of Lithium based ceramics with some inherent open porosity. These pebble beds are subjected to very high temperature (around 600C) in additional to neuronic heating and mechanical stresses. Hence, understanding their thermo-mechanical behaviour is imperative to the successful design of breeder units of fusion reactors. In addition, the pebble beds are expected to result in maximum possible tritium breeding while guaranteeing thermal and mechanical stability. The thermal and mechanical integrity of these granular systems depend closely on the packing structure of the pebbles in breeder units. In this talk we show our recent studies on heat transfer and packing structures of such granular systems and then show some correlations useful for design of pebble beds.

Introduction to Inverse Problems in Elasticity

A N Reddy
Department Mechanical Engineering, IIT Guwahati

Abstract:

In this work, two inverse problems in elasticity are introduced namely Cauchy problem and inverse boundary value problem (IBVP). The Cauchy problem is related to estimation of forces from the inconsistency data that is available from the experimental measurements. On the other hand, IBVP is deals with the estimation of mechanical properties such as Young's modulus and Poisson's ratio for a given input boundary data of forces and displacements. Although both are two different type problems, they belong to the class of ill-posed problems, i.e., solutions are highly sensitive to the presence of errors in the input data. Both problems have many applications in biomechanics and health monitoring of structures.

Two solution procedures to the Cauchy problem are discussed in this work. First solution procedure is natural extension to the solution of forward problem. However, rectangular matrices arise in obtaining the solution. Hence, pseudo-inverse is used for obtaining the forces. This procedure work if the error in the input data is very less (less than 3%) and usually error in experimental data is more. Another solution procedure is proposed based on optimization techniques to eliminate the shortcoming. The second solution procedure tolerates about 15% error in the input data which is sufficient to obtain forces from experimental data.

The inverse boundary value problem is formulated for estimating Young's modulus distribution with motivation to detect tumors in the biological tissues. Unlike previous problem, it is very difficult to get the accurate solution in the general framework. The numerical issues that are involved in getting the solution will be presented with examples.

Mechanical properties of idealised inverse opal lattice

Syed N. Khaderi
Department of Mechanical and Aerospace Engineering, IIT Hyderabad

Abstract:

The idealised inverse opal lattice is a network of slender struts that has cubic symmetry. We analytically investigate the elastic properties and yield behaviour of the idealized inverse opal lattice. It is found that the inverse opal lattice is bending-dominated under all loadings, except pure hydrostatic compression or tension. Under hydrostatic loading, the lattice exhibits a stretching dominated behaviour. Interestingly, the Young's modulus and shear modulus are equal in magnitude. The analytical estimates for the elastic constants and yield strength are validated by performing unit-cell finite element simulations. The buckling of the lattice is also investigated using the Bloch-wave method.

Experimental and numerical studies on failures of composite laminates containing embedded wrinkles

Lala Bahadur Andraju, Gangadharan Raju
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Abstract:

The demand for the composite materials has been increased anonymously from past few decades in the critical load bearing structures under various loading conditions. This requires a great effort in research areas such as development of different methodologies for life prediction, characterization of damage evolution and mechanisms at multiple scales. The main objective of this research is to study the effect of manufacturing defects like wrinkles and the severity of wrinkle parameters on the strength and failure criteria of the composites. In recent years the research is going in two different paths with linked to each other. The first one is the non-destructive evaluation (NDE) techniques for predicting the damage initiation, propagation and the mechanisms behind the failure of composites. Second approach is related to development of computational model to study failure mechanisms of composites in finite element framework.

Initially, various manufacturing approaches are explored to fabricate composite specimen that contain controlled and characterized manufacturing defects namely, wrinkles of various size, shape and location. Experiments will be conducted on these specimens, AE and ultrasonic techniques are used to investigate the damage mechanisms and their interaction that leads to the failure of the structure completely. Various AE parameters like cumulative energy, hits and frequency content of waveforms facilitates quantitative information about the different failures in composite specimens with applied load. Subsequently, damage models like cohesive zone, fiber failure, fiber kinking and matrix cracking are developed for studying the damage initiation and progression in composite laminates. The developed damage models are then used in a finite element framework to investigate the failures in laminated composite under various loading conditions. In the present study hybrid brick elements are going to be used in place of regular displacement brick elements to develop the damage models. These damage models would be validated with the experimental AE and ultrasonic results so that it can be confidently applied to damage predictions in component level testing. Finally, the aim is to create a virtual tool for characterization of damage evolution and mechanism of laminated composites.

Keywords: wrinkles in composites, NDE techniques, damage models, hybrid brick elements.

Limit points in the free inflation of a magnetoelastic toroidal membrane

Narravula Harshavardhan Reddy and Prashant Saxena
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Abstract:

Nonlinear elastic membranes find numerous applications in the fields of structural and aerospace engineering, and safety. Inflatable balloons, roof-tops, air bags, diaphragm valves, and protecting/cushioning membranes are some examples. Many biological materials including cell membranes, tissues, arterial walls also fall in this material category. One common phenomenon native to inflation of membranes is the elastic limit-point instability–a bifurcation point at which the membrane begins to deform enormously at the slightest increase of pressure. Increasing surface area and decreasing thickness call for a local maximum in the inflating pressure. Beyond this point, multiple equilibrium states are possible for the membrane (generally, only the stable ones are shown in a pressure-stretch plot).

Magnetoelastic polymers have the ability to respond mechanically to an applied magnetic field and vice versa. They typically contain numerous tiny ferromagnetic particles (like iron) embedded in a polymer matrix such as rubber. In the presence of an external magnetic field, individual magnetization vectors of the ferromagnetic particles align with the applied field and the resulting interaction leads to a change in the observed macroscopic stiffness and dimensions of the polymer. This possibility to alter mechanical properties has found applications in sensors, actuators and active vibration control. An external magnetic field can alter the overall stiffness of a magnetoelastic material and hence the critical point or limit point pressure. In addition, just like the traditional critical point due to elastic stiffness, it is possible to have a different critical point due to the extra stiffness caused by a sufficiently strong non-uniform magnetic field. In the case of magnetoelastic materials, there is another possible phenomenon, which we call magnetic limit-point instability, a state referring to the non-existence of an equilibrium state – either stable or unstable.

In this work, we are concerned with such instabilities in an incompressible isotropic magnetoelastic toroidal membrane with an initial circular cross-section. An external magnetic field is generated using a circular current carrying loop placed inside the membrane in addition to inflation by a uniform hydrostatic pressure. For simplification, we assume that the material is weakly magnetized and hence neglect the self-generated magnetic field. An energy formulation based on magnetization is used to model the magneto-mechanical coupling along with a Mooney-Rivlin constitutive model for the elastic strain energy density. Numerical results show that the magnetic field strongly influences the location of elastic limit points and in some cases can cause them to vanish. We also show that the initial circular cross-section of toroidal membrane doesn't remain circular under a large pressure or magnetic loading, thereby departing from a commonly used assumption by early researchers. While the quantitative results obtained here are specific to the toroidal geometry, the deformation behaviour can be generalised to any magnetoelastic membrane.

Nonlocal Structural Analysis

P. Raghu, A. Rajagopal
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Abstract:

Idealization of materials as a continuum has serious limitations in analysing the material at smaller length scale such as nano scale. This is mainly due to the fact that the classical continuum model lacks an internal characteristic length scale. Every material possesses inhomogeneity at smaller length scale which induces a strongly nonlinear behaviour and local weakness of a material which is a material instability that triggers strain localization. Experimental evidence suggests that at small scale, the continuum description is no longer valid and to be replaced by a discrete model. On the other hand atomic and molecular models are computationally expensive [1]. Improved formulations were proposed by considering elastic materials with long range cohesive forces, elastic media with micro structure and continuum approaches derived from an atomic lattice theory by Edelen et al. [2] and Eringen [3]. Nonlocal continuum models attempt to extend the continuum mechanics approach to smaller length scales by introducing a length scale term in the constitutive relations. These nonlocal constitutive relations are proven to disappear the singularity at the crack tip (see [4] and [5]). Nonlocal models can also capture the size effects observed in experimental and discrete simulations. Hence the approach towards the nonlocal continuum mechanics is necessary to analyse the small scale structures, to account for the size effects, to address the singularity problems at the crack tip and etc.

In this work, we present the necessity of nonlocal approach and its effect on the behaviour of laminated composite structures using Eringen's [3] nonlocal model.

References:

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Dynamic Interface Failure

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Abstract:

The dynamic interface failure phenomena are studied using numerical methods. Isotropic materials, being degenerate materials, are analyzed using the spectral method proposed by Geubelle & Rice (1995) [1]. The spectral method gives a relation between the stresses on crack surfaces and the crack opening displacement. A general solution method is proposed for dynamic interface failure in anisotropic bi–materials. The proposed method uses the analytical solution of Wu (2003) [2]. The solution is represented by the eigenvectors and eigenvalues of a six-dimensional matrix. The characteristic equation of the matrix is a function of the stiffness matrix, spatial coordinates, and time. A cohesive zone is used to control the interface opening displacement. Numerical results for a pristine interface, a sharp crack, and an open crack are presented for isotropic materials.

References:

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Fiber Breakage analysis in Single Fiber Composite

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Abstract:

Single fiber composite (SFC) helps in understanding the failure processes in composites at micro-mechanical level. Failure in Composites starts at the fiber breakage, as it is the main load carrying member. Other failures like fiber/matrix interface failure and matrix cracking emanate at the site of fiber failure. Progressive Damage Analysis (PDA) is used to conduct the fiber failure simulation. High Fidelity Generalized Method of Cell (HFGMC) method is employed to carry out the stress analysis. It is capable of capturing gradient in the local stresses effectively at the fiber/matrix interface. The maximum principle stress criteria is used for damage detection in PDA. Matrix is assumed to take large strains before failure, thus making the fiber to break successively. The damage modeling is carried out with the sudden material property degradation rule. The PDA has been devised in Fortran fixed form language. The result of this work shows the stress distribution in the SFC with fiber breakages. Distribution of stress at the site of fiber failure gives the direction of matrix crack propagation and matrix/fiber interface failure.

References

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Smoldering experiments and simulations of Incense sticks

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Abstract

Smoldering is the phenomenon of slow burning with smoke but without flame. This phenomenon is simulated through finite element analysis and is validated by the experiments. The surface temperature of the smolder zone is obtained through using Infra-Red Thermography (IRT) performed in the ambient environment. Temperature profiles with and without ash are obtained along with the rate of burning. Peak temperature observed in the experiments is of the order of 600°C [1]. Currently, Inverse methods are used to estimate the heat flux from the temperature profile.

***Keywords*:** Smoldering, Incense stick, Heat source model, Infrared Thermography.

References:

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Study of moisture degradation in Aramid and Para Aramid fiber

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Abstract:

This study proposes to indication the impact of the hydrolytic degradation on the properties of the Kevlar and armos fiber. High performance aramid fibers play an vital element of many civilian and military applications. It is hard to discriminate free water on the surface from bound water with a traditional balance. The data collected in this study was then compared and contrasted to known Kevlar studies, identifying similarities, differences, and potential trends. A DSC provides a method to precise measurements to carry both mass loss and heat flow as function of time of time and temperature. The TGA/DSC1 has so far provided a reliable and precise method of monitoring mass loss in high performance fibers at a constant temperature but further refinement is needed as a) Analysis of the heat flow curve b) A baseline should be established for as received and dried fibers.

Keywords: Kevlar , Armos fiber, DC. TGA.

Optimization of Structures: Theory and Applications (using ANSYS)

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[2]Dr. Surendra Nadh Somala, Assistant Professor, Dept. of Civil Engineering, IIT Hyderabad

Abstract:

The use of optimization techniques in the design process of a structural element has earned significant importance in recent times. These techniques are employed to achieve structural goals like performance, strength etc., by cutting on development costs and time. Currently, the concept was also extended to Civil Engineering domain to optimize structural elements like trusses and frames. However, finding the optimum size/shape/layout of the material by parametrically changing the input design parameters is an iterative process and requires high computational power and involves cost. Hence various techniques or algorithms such as Reliability Based Design Optimization (RBDO), Bi-directional Evolutionary Structural Optimization (BESO) were developed to find the optimum shape, size and topology of the structural element. This paper will highlight the details of each such method that are practised in industry along with necessary background to the topic. Also, a small study for size optimization on an element with circular section using ANSYS workbench is illustrated as an application of concept. A preliminary study showed around 6% reduction in size of an element for the given input parameters and constraints.

References:

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Calibrating parameters for modified embedded atom method potential of tin (Stannum) using MPC tool

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Abstract:

Molecular dynamics is the simulation technique used at the atomistic scale. The interaction among atoms is of interest, and the atomic structure is evolved in time using Newton's equation of motion. The interatomic potential supplied as input for the simulations. Embedded atom method (EAM) [1] does not account for the angular forces in the interaction of atoms. Hence modified embedded-atom method (MEAM) [2] was developed in which the angular forces are also included.

MEAM is widely used in the area of Integrated computational materials engineering (ICME) [3] at the atomic scale. However, the MEAM potentials available for different atom types is limited. These potentials are available for the majority of metals except Sn and a few others. We develop the calibrating parameters for MEAM potential for Sn using MPC tool. The electronic scale simulation data required for the calibration is done using Quantum Espresso [4]. Eventually, we intend to study the elastic properties of two-dimensional hexagonal allotrope of tin stanene using Molecular dynamics using the computational tool LAMMPS. Stanene is considered to have 2D honeycomb lattice structure along with the other group-IV 2D structures like graphene, silicene, and germanene. The relaxed structure of stanene in hexagonal honeycomb structure is found to have a lattice parameter a_o=4.6217 A^o.

References:

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