Lipschitz regularization for Data Driven Computational Damage Mechanics

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In the Finite Element simulations (FE) of materials that undergo softening, regularization is necessary to make the problem well-posed. The regularization introduces a length scale into the problem whereby the results of the FE simulations become mesh independent [1]. The regularization is typically introduced in many ways - for instance, using the gradient of damage variables, using a non-local strain measure for the computation of damage, using a non-local energy release rate for damage computation, etc. Most of the regularization techniques used in the literature rely upon the introduction of the integral or the gradient of some internal variable.

The Data Driven Computational Mechanics (DDCM) has been introduced to perform (FE) simulations without recourse to the constitutive model to describe the behavior of the material [2]. The stress-strain pairs obtained from experiments or other micro-scale simulations are used as the input to perform the FE simulations thereby bypassing the material model altogether. By minimizing a certain distance functional, the *mechanical* and *material* states are found that satisfy the equilibrium equations as well as describe the material behavior. In practice an alternated minimization scheme is used. Convergence is said to have occurred when the mechanical and material states do not change any more between the iterations. It shall be noted that the internal variables that are typically used to describe the inelastic behavior of the materials are not explicitly introduced in the context of DDCM.

Simulations can be performed using DDCM with the data that reflects the softening behavior of the material, for instance from damage. As already mentioned, the internal variables that are typically used to describe the inelastic behavior of the material are not explicitly introduced in DDCM. Hence, the techniques that regularize the problem using for instance the gradient of damage or computing damage from non-local strain measures cannot be used in this case. The current study introduces a regularization technique using the strain variable, wherein the gradient of strain is bound by a certain value as was done in [3]. In [3], a constitutive model has been used to describe the behavior of the material. The introduction of a bound prevents the strains from localizing within an element (or on sets of measure zero) thereby introducing non-locality and a length scale into the problem. In the 2D setting, the gradient of strain is replaced by an equivalent measure that is objective. The bounds are placed on this equivalent strain gradient measure instead.

This study first discusses and describes the regularization technique in a 1D setting and compares its performance with the strain gradient models. Secondly, it extends the formulation to the 2D setting, where the constraint becomes non-linear. The effectiveness of this formulation will be tested for multiple cases and the results will be compared with that of the regularization techniques in the continuum setting. Overall, this methodology can be seen as a first step towards the introduction of regularization in the context of DDCM to simulate the materials undergoing softening.

References

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