Colour-Field Based Particle Categorization for Residual Stress Detection and Reduction in Solid SPH Simulations

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Abstract

Residual stress remains in an object even in the absence of external forces or thermal pressure, which, in turn, may cause significant plastic deformations. In case the residual stress creates unwanted effects on the material and so is undesirable, an efficient solution is necessary to track and eliminate this stress.

Smoothed Particle Hydrodynamics has been extensively used in solid mechanics simulations and the inherent colour-field generation approach is a promising tracker for the residual stress.

In this paper, we propose a way to use the colour-field approach for eliminating the residual stress and prevent the undesirable premature failure of solid objects.

Introduction

Residual stresses describe any stress remain in the material even after the external forces and thermal effects are excluded from the environment. These stresses may originate from many causes, e.g. cooling rates, volume changes, etc. and they may be created by welding, rolling, forging, casting, machining, heat treatments or surface treatments. After that point, residual stress is generated when an object is stressed beyond its elastic limit, resulting in plastic deformation.

Residual stress should be managed properly for the design, manufacturing, and maintenance phases. Although it may be desirable in some certain conditions, residual stress generally causes the material to fail prematurely. It may affect the fatigue life, stability, resistance and also brittle fractures of objects. Our contribution in this ongoing work is to eliminate the undesired residual stress behaviour from solid mechanics simulations by applying a colour-field technique which is extensively used in SPH fluid simulations. Colour-field approach helps us to identify the particles with potential residual stress which, in turn, are handled differently to reduce the overall stress.

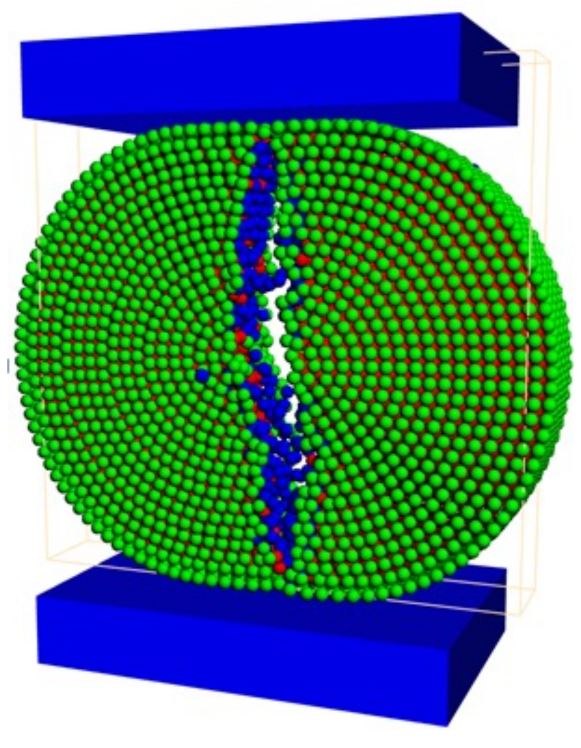

Figure 2. Surface particle generation (green), inner layer additional surface set particles (red) and completely fully particles (blue) during a brittle fracture .

SPH

SPH is a method of discretizing spatial quantities using a set of particles equipped with a kernel function. Each particle is defined by a position, mass and a support radius.

The word "smoothed" in SPH comes from the smoothing operation which actually means calculating any physical quantity of the particle using the weighted sum of the same quantity of the neighboring particles that lie in the range of a kernel function. So, after the continuous approximation is discretized, the smoothing operation looks as:

$$A_a = \sum_b m_b \frac{A_b}{\rho_b} W(\mathbf{x}_a - \mathbf{x}_b, h)$$

where A is an arbitrary scalar quantity, $\mathbf{x}$ is the position, b is the iterator over all contributing particles and h is the smoothing length.

SPH FOR SOLIDS

SPH should be extended so that it may reflect the solid behaviour and yielding criterion. Therefore, we firstly implemented elastoplastic solid behaviour in our system by integrating the momentum equation:

$$\frac{\mathrm{d}v^i}{\mathrm{d}t} = \frac{1}{\rho}\frac{\partial \sigma^{ij}}{\partial x^j} + g^i$$

$$\sigma^{ij} = -P\delta^{ij} + S^{ij}$$

with pressure P, deviatoric stress tensor S. Stress can be computed using Hooke's Law. At this stage, maximum distortion energy criterion can be introduced to the system to estimate the yield of ductile materials. We can even compare the material's yield stress to Von Misses stress to observe the its resistance and yielding thresholds. Our main focus in this ongoing work is to determine particles which are potentially carrying residual stress. We therefore propose to use the colour field approach to categorize the solid particles. We can identify a particle as a surface particle in two conditions combined: 1) if it has less than a certain number of neighbouring particles and 2) if its surface normal n is showing more than a meaningful threshold. Surface normal in this situation can be computed as:

$$\mathbf{n} = \nabla c_s$$

$$c_s(\mathbf{p}_i) = \sum_b \frac{m_b}{\rho_b} W(\mathbf{p}_i - \mathbf{p}_j, h)$$

After identifying surface particles, we generated one more additional layer right behind the surface particles and we constrain those two sets to apply only hydrostatic stress to other particles

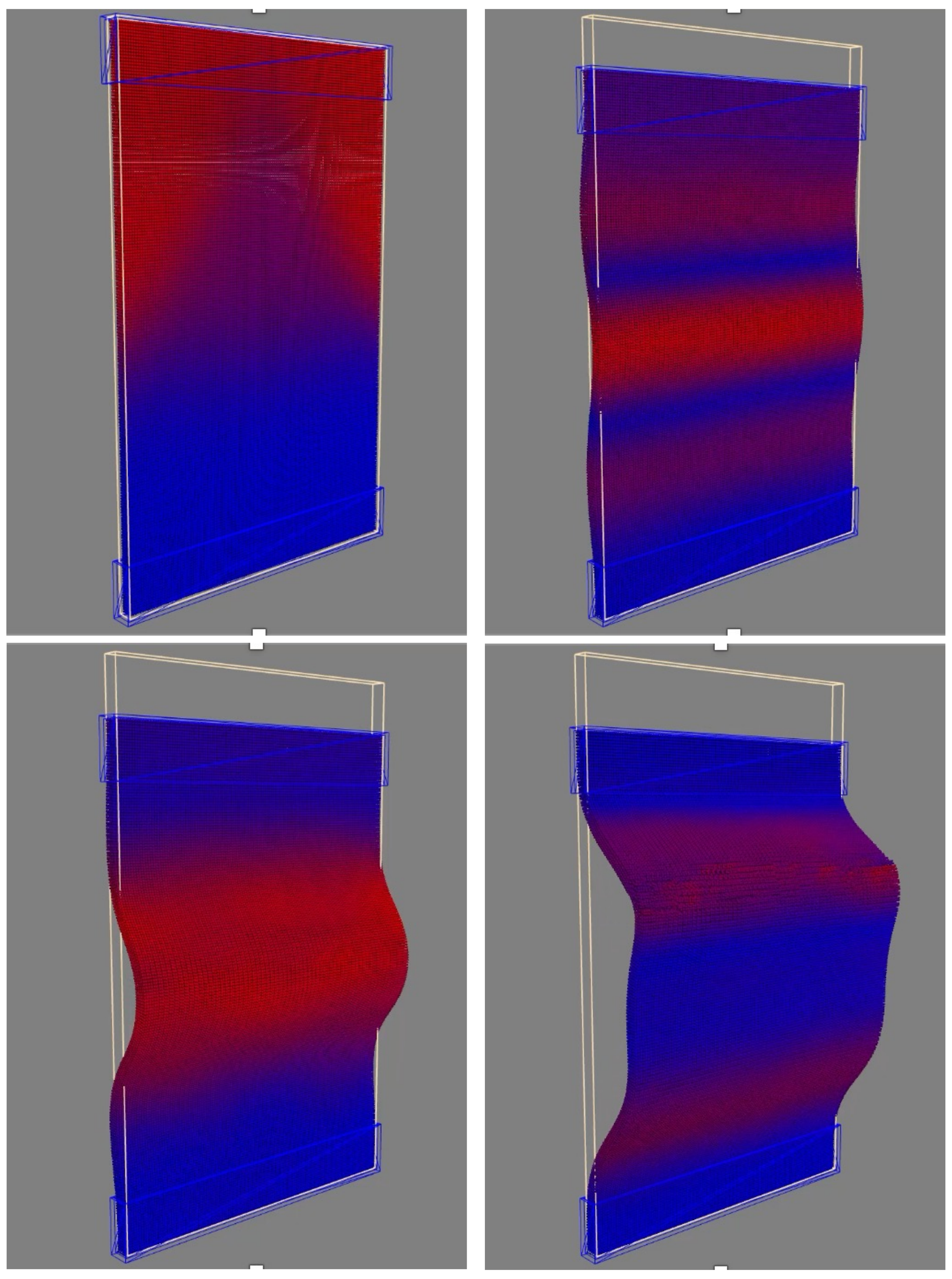

Figure 1. Compressed ductile material implemented with our SPH model and visualized with pressure-based colouring.

Results

During this approach, we observed that the stability of the system improved significantly and we could use larger time steps for our simulations. To be specific, our simulation time steps has been increased almost twice for all presented scenes. Additionally, we could prevent all undesired crashes and undesired forces from our system.
As an unexpected effect, we also noticed that we could simulate brittle fractures without using an ad-hoc damage model

Conclusions

In this paper, we presented a technique to improve the stability of a solid system simulation by using smoothed particle hydrodynamics. Based on the conventional SPH model, we integrated elastoplastic solid physics and used the idea of surface extraction for isolating the force computation on certain fields. We observed that the technique works well for both ductile and brittle materials.
This is obviously an ongoing work and needs further improvement. We plan to utilize more test scenes and various comparisons for different material properties in the future. Furthermore, we only discussed the general stability but we did not discuss the performance in detail. In the future, we would like to investigate parallelization techniques for the model.

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