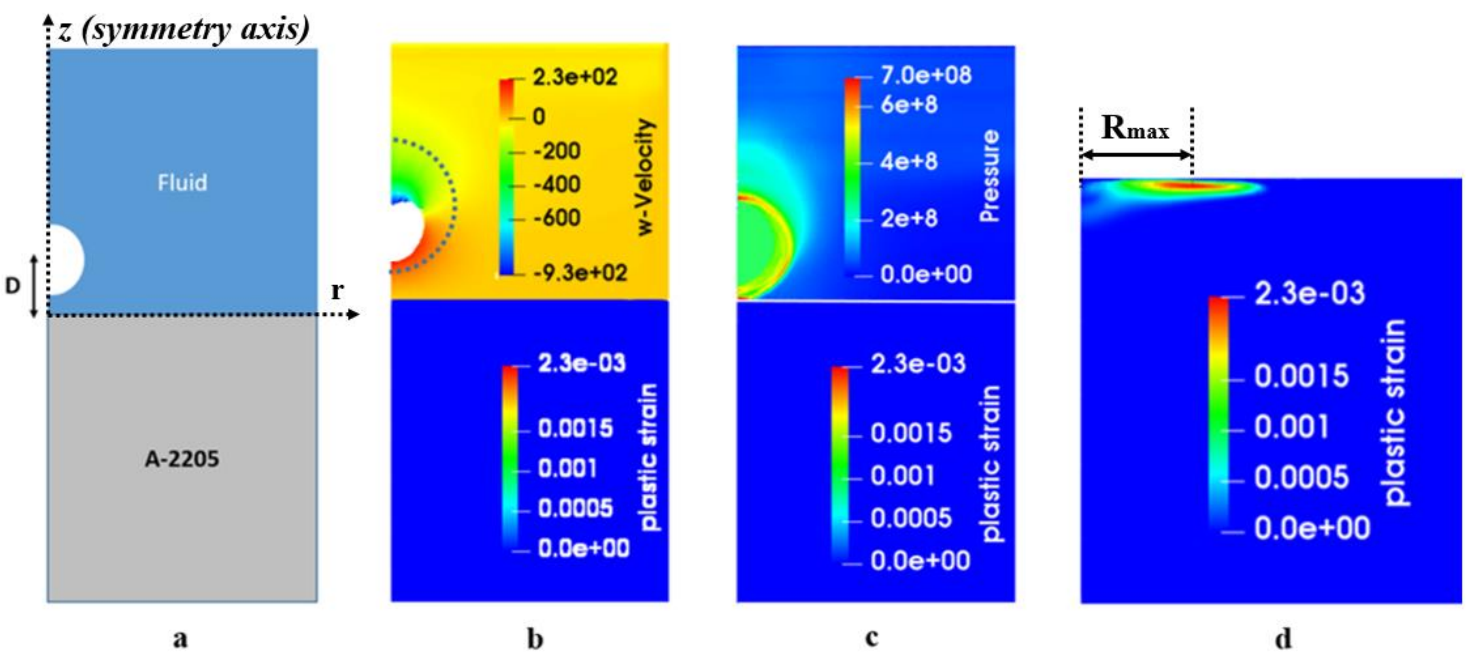
Summary of deliverable D1.6: Fluid-structure Interaction in cavitation erosion

provided by ESR 3, Mr. Shrey Joshi, under the guidance of Prof. Marc FIVEL, Prof. Jean-Pierre FRANC & Dr. Giovanni GHIGLIOTTI, INP Grenoble, August 2018

The deliverable 1.6 refers to development of a Smoothed Particle Hydrodynamics (SPH) Fluid-Structure Interaction (FSI) cavitation solver to understand the phenomenon of material deformation under cavitation load better. This summary presents a brief overview of the methodology used to solve a fluid-structure interaction simulation of a bubble collapse over a deformable solid medium. The fluid solver and the solid solver are validated against Rayleigh-Plesset spherical bubble collapse case and FEM solver respectively. The fluid solver is developed using an open source SPH code SPHYSICS_2D, the code is changed from 2D to 2D axisymmetric. The solid SPH solver is developed in-house in 2D axisymmetric, a novel scheme is derived to solve typical issues near symmetry axis in the solid axisymmetric SPH solver. The solid solver has the capability to solve for non-linear isotropic hardening with strain rate effects (commonly known as Johnson-Cook plasticity model).

A case each for a detached and an attached cavity is simulated using the FSI solver, the results show that for the same magnitude of pressure wave initiating the collapse and the same size of the bubble, the micro-jet can produce twice the maximum plastic deformation compared to a shock wave, hence a micro-jet dominated impact would exhibit a smaller incubation time compared to the detached cavity. It is also observed that the volume of material that is plastically deformed in case of a micro-jet is miniscule compared to a shock wave impact (almost 800 times smaller). This would imply that even though the incubation time for material erosion might be lower for a micro jet collapse, the shock wave can plastify a much larger volume of material and so the erosion rate should be higher for a shock wave impact. Hence it could be inferred that the material erosion ability of a shock wave is much higher than a micro-jet.

An important and novel finding in the present study is the response of the material for a detached cavity where plastic deformation does not occur at the center of collapse but at an offset from the center. The results show that even though the pressure experienced by the material is the highest at the center, it does not produce the maximum plastic deformation. This is for the first time that such a phenomenon is reported in cavitation studies, we find that the phenomenon is linked to inertial effects where the material does not respond to the load as the rate of loading and unloading is extremely high. The effect is linked to the high loading and unloading rate near the center of the collapse due to the flat geometry of the solid medium. The study clearly demonstrate that maximum pressure does not always correspond to the location of maximum plastic deformation or material erosion.



(a) Sketch of the initial simulation domain for axisyymmetric SPH FSI simulation of a detached cavity, (b) shows contours of axial velocity in the fluid and plastic strain in the solid, a micro-jet formation can be observed after the pressure wave from the top of domain hits the bubble (the dotted semi-circle represents the initial bubble), (c) contours of pressure in the fluid and plastic strain in the solid, a shock wave genrated due to the bubble collapse can be observed as it juts recahes the interface, (d) plastic strain contours in the solid at the end of the simulation, the maximum plastic strain occurs at a radial offset of R_{max} from the symmetry axis.

Fluid-Structure Interaction simulations for different stand-off ratios, driving pressure and bubble radius have been computed. Results show that for varying stand-off ratio while keeping the bubble radius and driving pressure constant, the attached cavities (SR<=1) show a higher plastic strain magnitude and a higher absorbed energy density which would suggest a quicker incubation time. However, the volume of plastic defamation zone is much lower in attached cavities thus the total absorbed energy and the erosion rate would be higher for a detached cavity compared to an attached one.

The increase in driving pressure seems to show expected results where both the absorbed energy density (hence incubation time) and the total absorbed energy (hence erosion rate) seem to increase with increasing driving pressure. The change in bubble radius while keeping other parameters constant seem to not affect the magnitude of plastic strain and absorbed energy density much, which would suggest that irrespective of the size of the cavitation bubble, the incubation time should remain similar. However, since the volume of plastically deformed zone goes almost linearly with the bubble size, the total absorbed energy or the erosion rate increases significantly with increasing bubble size.

Fluid-Structure Interaction studies in the past have not considered strain rate sensitivity while defining the plasticity model. The strain rate effects suggest that the magnitude of plastic strain is over predicted while using plasticity models that do not use strain rate sensitivity. The over prediction of the magnitude of plastic strain of around 60% for detached cavities presented in the paper and around 200% for attached cavities presented in the paper is observed. This would lead to an under prediction of incubation time and over prediction of erosion rate while using strain rate insensitive plasticity models.